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Laboratory Evaluation of Light Obscuration Particle Counters used to Establish use Limits for Aviation Fuel

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U.S. Army Tank Automotive Research,
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U.S. Army Tank Automotive Research Development and Engineering Center

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used to Establish use Limits for Aviation Fuel

Joel Schmitigal
Force Projection Technology

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Table of Contents

List of Figures	iv
List of Tables	v
Appendix A Online Evaluation 1	vi
Appendix B Online Evaluation 2	vii
Appendix C Online Evaluation 3	ix
Appendix D Bottle Sample Evaluation	x
Appendix E Test Dust and Free Water Test Dust Evaluation	xi
Introduction	1
Approach	2
Analysis	4
ISO 12103-1 A3 medium test dust evaluation	4
ISO 12103-1 A2 fine test dust evaluation	5
ISO 12103-1 A1 ultrafine test dust evaluation	6
Red Iron Oxide test dust evaluation	7
Free water evaluation	7
Test dust and free water test dust evaluation	8
Conclusions	8
References	9
List of Symbols, Abbreviations, and Acronyms	10

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Appendix A	Online Evaluation 1	1
Appendix B	Online Evaluation 2	1
Appendix C	Online Evaluation 3	1
Appendix D	Bottle Sample Evaluation	1
Appendix E	Test Dust and Free Water Test Dust Evaluation	1

List of Figures

Figure 1. Correlation of total particles $\geq 4\mu\text{m}$ to theoretical concentration (mg/L) of ISO 12103-1 A3 medium test dust.	5
Figure 2. Correlation of total particles $\geq 4\mu\text{m}$ to theoretical concentration (mg/L) of ISO 12103-1 A2 fine test dust.	6
Figure 3. Correlation of total particles $\geq 4\mu\text{m}$ to theoretical concentration (mg/L) of ISO 12103-1 A2 fine test dust.	7
Figure 4. Water Droplet Distribution.....	8

List of Tables

Table 1. Test dust particle size distribution as determined by sieving	4
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Appendix A Online Evaluation 1

Table A 1 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 1.0 mg/L concentration.	1
Table A 2 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 0.5 mg/L concentration.	1
Table A 3 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 0.25 mg/L concentration.	2
Table A 4 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 1.0 mg/L concentration.	2
Table A 5 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.5 mg/L concentration.	3
Table A 6 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.25 mg/L concentration.	3
Table A 7 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 1.0 mg/L concentration.	4
Table A 8 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 0.5 mg/L concentration.	4
Table A 9 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L concentration.	5
Table A 10 – Evaluation 1 IP 564 particle count data for red iron oxide test dust at 1.0 mg/L concentration.	5
Table A 11 – Evaluation 1 IP 564 particle count data for red iron oxide test dust at 0.5 mg/L concentration.	6
Table A 12 – Evaluation 1 IP 564 particle count data for red iron oxide test dust at 0.25 mg/L concentration.	6
Table A 13 – Evaluation 1 IP 564 particle count data for red iron oxide test dust with free water.	7
Table A 14 – Evaluation 1 IP 564 particle count data for 5 ppm free water.	7
Table A 15 – Evaluation 1 IP 564 particle count data for 7 ppm free water.	8
Table A 16 – Evaluation 1 IP 564 particle count data for 12 ppm free water.	8
Table A 17 – Evaluation 1 IP 564 particle count data for 15 ppm free water.	9
Table A 18 – Evaluation 1 IP 564 particle count data for 40 ppm free water.	9
Table A 19 – Evaluation 1 IP 564 particle count data for water slug test.	9

Appendix B Online Evaluation 2

Table B 1 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A3 medium test dust at 2.5 mg/L concentration.	1
Table B 2 - Evaluation 2 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 2.5 mg/L concentration with free water.	1
Table B 3 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A3 medium test dust at 2.0 mg/L concentration.	1
Table B 4 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A3 medium test dust at 1.0 mg/L concentration.	2
Table B 5 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A3 medium test dust at 0.5 mg/L concentration.	2
Table B 6 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A3 medium test dust at 0.25 mg/L concentration.	2
Table B 7 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A2 fine test dust at 2.5 mg/L concentration.	2
Table B 8 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A2 fine test dust at 2.0 mg/L concentration.	3
Table B 9 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A2 fine test dust at 1.0 mg/L concentration.	3
Table B 10 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A2 fine test dust at 0.5 mg/L concentration.	3
Table B 11 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A2 fine test dust at 0.25 mg/L concentration.	3
Table B 12 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 2.5 mg/L concentration.	4
Table B 13 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 2.0 mg/L concentration.	4
Table B 14 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 1.0 mg/L concentration.	4
Table B 15 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 1.0 mg/L concentration and 10 ppm free water.	4
Table B 16 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 0.5 mg/L concentration.	5
Table B 17 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L concentration.	5
Table B 18 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L concentration with 5 ppm free water.	5
Table B 19 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for red iron oxide test dust at 2.5 mg/L concentration.	5
Table B 20 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for red iron oxide test dust at 2.0 mg/L concentration.	6
Table B 21 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for red iron oxide test dust at 1.0 mg/L concentration.	6

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Table B 22 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for red iron oxide test dust at 0.5 mg/L concentration.	6
Table B 23 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for red iron oxide test dust at 0.25 mg/L concentration.	6
Table B 24 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for 5 ppm free water.	7
Table B 25 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for 10 ppm free water.	7
Table B 26 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for 20 ppm free water.	7
Table B 27 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for 30 ppm free water.	8
Table B 28 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for 40 ppm free water.	8

Appendix C Online Evaluation 3

Table C 1 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 1.0 mg/L concentration.	1
Table C 2 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 0.5 mg/L concentration.	1
Table C 3 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 0.25 mg/L concentration.	2
Table C 4 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 1.0 mg/L concentration.	2
Table C 5 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.5 mg/L concentration.	2
Table C 6 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.5 mg/L concentration.	3
Table C 7 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 1.0 mg/L concentration.	3
Table C 8 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 0.5 mg/L concentration.	3
Table C 9 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L concentration.	4
Table C 10 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L concentration and free water.	4
Table C 11 - Evaluation 3 IP 564 particle count data for red iron oxide test dust at 1.0 mg/L concentration.	5
Table C 12 - Evaluation 3 IP 564 particle count data for red iron oxide test dust at 0.5 mg/L concentration.	5
Table C 13 - Evaluation 3 IP 564 particle count data for red iron oxide test dust at 0.25 mg/L concentration.	5
Table C 14 - Evaluation 3 IP 564 particle count data for 5 ppm free water.	6
Table C 15 - Evaluation 3 IP 564 particle count data for 10 ppm free water.	6
Table C 16 - Evaluation 3 IP 564 particle count data for 20 ppm free water.	6
Table C 17 - Evaluation 3 IP 564 particle count data for 40 ppm free water.	7

Appendix D Bottle Sample Evaluation

Table D 1 – Bottle sample evaluation IP 564 particle count data for ISO 12103-1 A3 medium test dust at 1 mg/L and 2 mg/L.....	1
Table D 2 – Bottle sample evaluation IP 564 particle count data for ISO 12103-1 A2 fine test dust at 1 mg/L and 2 mg/L.....	2
Table D 3 – Bottle sample evaluation IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 1 mg/L and 2 mg/L.	3

Appendix E Test Dust and Free Water Test Dust Evaluation

Table E 1 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.25 mg/L concentration with low concentration free water.	1
Table E 2 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.25 mg/L concentration with high concentration free water.	2
Table E 3 – Evaluation 1 IP 564 particle count data for Red Iron Oxide test dust at 0.25 mg/L concentration with free water.	3
Table E 4 – Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L with low concentration free water.	4
Table E 5 – Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L with medium concentration free water.	4
Table E 6 – Evaluation 3 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 0.25 mg/L with free water.	5
Table E 7 – Evaluation 3 IP 564 particle count data for ISO 12103-1 A1 fine test dust at 0.25 mg/L with free water.	6

Introduction

The U.S. Army maintains the mission of providing quality fuel to U.S. and Allied troops in tactical environments. Presently, requirements as outlined require a dedicated group of specifically trained fuels personnel to perform several tests per day per installation looking for traces of sediment and water in the fuel (1) (2).

The Army utilizes several techniques to ensure that aviation fuels are clean and dry. Despite the best of intentions the current test methods utilized by the Army have several drawbacks including: timeliness of data due to the turn-around time needed to get the test results, operator subjectivity, lack of detailed analysis, and limitations in providing reliable data. For these reasons the Army has been actively working to develop new methods for monitoring fuel contamination (3) (4).

The Army utilizes ASTM D4176 – Standard Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures), as a final check of fuel to ensure aviation fuel is clear and bright before flight operations.

Fuel filter effectiveness is evaluated by quality assurance testing though conducting periodic fuel sampling for gravimetric analysis. The Army currently utilizes two methods for measuring particulate contamination by gravimetric analysis: ASTM D2276 - Standard Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling, and ASTM D5452 - Standard Test Method for Particulate Contamination in Aviation Fuels by Laboratory Filtration. Additionally free water content is determined by performing ASTM D3240 – Standard Test Method for Undissolved Water in Aviation Turbine Fuels, commonly termed AquaGlo testing.

Current standards specify limits for free water and particulate matter in aviation fuels. Specifically, free water contamination in jet fuel cannot exceed 10 parts per million (PPM) (1) and particulate matter contamination cannot exceed 2.0 mg/L for Intra-Governmental transfer receipts and 1.0 mg/L on issue to aircraft, or up to 10 mg/L for product used as a diesel product for ground use (1) (2) (5). At a minimum free water and particulate by color (as specified in the appendix of ASTM D2276) are checked daily, while filter effectiveness is checked every 30 days by gravimetric analysis (ASTM D2276).

One of the problems with the gravimetric methods is the poor repeatability and reproducibility of the methods, ASTM D2276 has a repeatability of 0.25 mg/L and reproducibility of 0.62 mg/L at the 1.0 mg/L contaminate level based on a 5 liter sample, whereas the Army utilizes 1 liter samples increasing the associated error. While the published repeatability and reproducibility of ASTM D5452 only spans from 0 to 0.6 mg/L, applying the provided formulas to the 1.0 mg/L contaminate level provides a repeatability of 0.42 mg/L and reproducibility of 0.73 mg/L. Sample volume used to calculate these values is not provided in ASTM D5452, but again 5 liter samples were used to develop these formulas used for these calculations.

The Energy Institute (EI) has published guidance documents and test methods relating to fuel quality measurement using electronic sensors. In February 2012 the second edition of EI 1598 *Design, functional requirements and laboratory testing protocols for electronic sensors to*

monitor free water and/or particulate matter in aviation fuel (6) was published. In August 2012 EI published the first edition of EI 1570 *Handbook on electronic sensors for the detection of particulate and/or free water during aircraft refueling* (7).

The U.S. Army Tank Automotive Research Development and Engineering Center (TARDEC) has been actively perusing advanced technologies to monitor aviation fuel for particulate and water contamination. The application of light obscuration particle counters for this purpose has risen to the top of available technologies in terms of performance and availability. The use of particle counting and automatic particle counters for monitoring contamination is frequently used in the hydraulics/hydraulic fluid industry. In 1999 ISO adopted ISO 11171 *Hydraulic fluid power — Calibration of automatic particle counters for liquids* (8), replacing ISO 4402, as an international standard for the calibration of liquid particle counters giving NIST traceability to particle size measurement, and providing an area equivalent diameter of particles measured. To simplify the reporting of particle counter data international standard ISO 4406:1999 *Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles* (9) by grouping the numbers of particles into broad classes or codes. Generally an increase in one ISO code number is caused by a doubling of the contamination level. EI has also published three standard test methods for evaluating the particulate matter of fuels using light obscuration particle counters; IP 564 – *Determination of the level of cleanliness of aviation turbine fuel – Laboratory automatic particle counter method* (10); IP 565 – *Determination of the level of cleanliness of aviation turbine fuel – Portable automatic particle counter method* (11); IP 577 – *Determination of the level of cleanliness of aviation turbine fuel – Automatic particle counter method using light extinction* (12). ASTM International adopted ASTM D7619 *Standard Test Method for Sizing and Counting Particles in Light and Middle Distillate Fuels, by Automatic Particle Counter* (13), which utilizes the same instrumentation as IP 565.

As a result of laboratory testing, the U.S. Army proposed a working cleanliness limit (modified from ISO 4406) of 19/17/14/13 utilizing the 4µm (c)/ 6µm (c)/ 14µm (c)/ 30µm (c) size channels (4). The 30µm (c) size is included for the detection of free water in the fuel. The proposed ISO code limits of 19/17/14/13 are based on the 1.0 mg/L concentration levels for the A1 and A2 test dusts, and down to a 5 ppm free water presence.

Approach

The test consisted of the manufacture and testing of contaminated fuels for both online and bottle samples. The online testing was conducted three separate times by The US Army TARDEC Fuels and Lubricants Research Facility at the EI 1581 test facility at Southwest Research Institute. Bottle samples were prepared and analyzed in TARDEC's Fuels and Petroleum, Oil & Lubricants (POL) Laboratories at the Detroit Arsenal.

The online procedure for evaluating the light obscuration particle counters was modified from the concepts found in Energy Institute (EI) 1598 – Design, functional requirements and laboratory testing protocols for electronic sensors to monitor free water and/or particulate matter in aviation fuel (6). The test plan looked to determine if the light obscuration particle counters

could differentiate between the various types and quantities of standard test dusts and free water and the combination of free water and test dust. Test dust selection was derived from EI 1598, EI 1581, and MIL-E-5007 (14). The water distribution was generated using the centrifugal pump specified in EI 1581, Specification and qualification procedures for aviation jet fuel filter/separators. The testing was performed with no filtration devices placed between the contaminant injection and the detection system. The test protocol is provided below:

1. Operate the system at approximately 105.7 gpm (400 lpm) in a single pass flow loop as specified in EI 1958. (contaminant is removed after electronic sensors)
2. Using clean, dry, Jet A, obtain baseline data for 30 minutes
3. Upon completion of baseline, obtain data when injecting ISO 12103-1 A1 ultrafine test dust at approximately 0.25 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0 mg/L, and 2.5 mg/L. Verify particulate contamination levels via ASTM D2276.
4. Upon completion of ISO 12103-1 A1 ultrafine test dust evaluation, perform analysis using ISO 12103-1 A2 fine test dust at approximately 0.25 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0 mg/L, and 2.5 mg/L. Verify particulate contamination levels via ASTM D2276.
5. Upon completion of the ISO 12103-1 A2 fine test dust evaluation, perform analysis using ISO 12103-1 A3 medium test dust at approximately 0.25 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0 mg/L, and 2.5 mg/L. Verify particulate contamination levels via ASTM D2276.
6. Upon completion of ISO 12103-1 A3 medium test dust evaluation, perform same analysis using Red Iron Oxide R-9998 (RIO) at approximately 0.25 mg/L, 0.5 mg/L, 1.0 mg/L, 2.0 mg/L, and 2.5 mg/L. Verify particulate contamination levels via ASTM D2276.
7. Upon completion of dirt tests, verify fuel is dry (ASTM D3240)
8. Obtain electronic sensor data using water contamination at approximately 5, 10, 20, and 40 ppm. Verify water contamination levels via ASTM D3240.
9. Upon completion of water tests, test ISO 12103-1 A1 ultrafine test dust and free water at 5ppm. Verify contamination levels via ASTM D2276 and ASTM D3240.

The particle size distribution for evaluated test dusts is provided in Table 1.

	A3 Medium Test Dust	A2 Fine Test Dust	A1 Ultrafine Test Dust	Red Iron Oxide R-9998
micron	% Less Than	% Less Than	% Less Than	
1	1.0 – 3.0	2.5 – 3.5	1.0 – 3.0	96.0
2	4.0 – 5.5	10.5 – 12.5	9.0 – 13.0	
3	7.5 – 9.5	18.5 – 22.0	21.0 – 27.0	
4	10.5 – 13.0	25.5 – 29.5	36.0 – 44.0	
5	15.0 – 19.0	31.0 – 36.0	56.0 – 64.0	
7	28.0 – 33.0	41.0 – 46.0	83.0 – 88.0	
10	40.0 – 45.0	50.0 – 54.0	97.0 – 100	
20	65.0 – 69.0	70.0 – 74.0	100	
40	84.0 – 88.0	88.0 – 91.0		
80	99.0 – 100	99.5 – 100		
120	100	100		

Table 1. Test dust particle size distribution as determined by sieving

Bottle samples were manufactured for verification purposes. Two liters of JP-8 fuel were cleaned by repeatedly filtering it through a 0.45µm filter until there were less than 50 particles per mL in the fuel. The fuel was then doped with a known amount of standard test dust, particle counted via IP 564, and 1 liter tested per ASTM D5452 to verify contaminate loading.

Analysis

ISO 12103-1 A3 medium test dust evaluation

ISO 12103-1 A3 medium test dust, having a particle size distribution found in Table 1, with 55% of its particulate content being larger than 10 µm provides a good representation of what would be clear evidence of a failed filter separator if particles of this size were found downstream of a filter separator. EI 1581 filters, with an approximate nominal micron rating of 0.4-1.0µm, are qualified with a 90% A1 ultrafine test dust – 10% red iron oxide mixture.

The three online evaluations of ISO 12103-1 A3 medium test dust at 1.0 mg/L saw an average of 1984, 2205, and 1635 particles ≥ 4 µm per milliliter measured via IP 564. The online evaluation for ASTM D7619 averaged 2607 particles ≥ 4 µm per milliliter for evaluation B. While the ASTM D2276 gravimetric measurements were recorded to be 0.25 mg/L and 0.27 mg/L for evaluation A, 0.16 mg/L and 0.33 mg/L for evaluation B, and 0.20 mg/L and 0.50 mg/L for evaluation C.

To determine the source of the error between the particle counter measurements and the gravimetric measurements, 10 bottle samples were prepared at TARDEC's Fuels and Petroleum, Oil & Lubricants (POL) Laboratories averaging 1800 particles ≥ 4 µm per milliliter when measured via IP 564. There was still a variation seen in the gravimetric measurements recorded by ASTM D5452, but not as large as seen when performing ASTM D2276 on the EI 1581 test

rig. The particle counting data of the bottle samples was found to be comparable to that seen in online evaluations leading to the conclusion that the EI 1581 injection levels are correct and that the low results from the ASTM D2276 testing is an artifact of that method. The correlation of particle counter data to the theoretical gravimetric concentration, and cross referenced to the bottle sample data, indicates that the collected data is valid Figure 1.

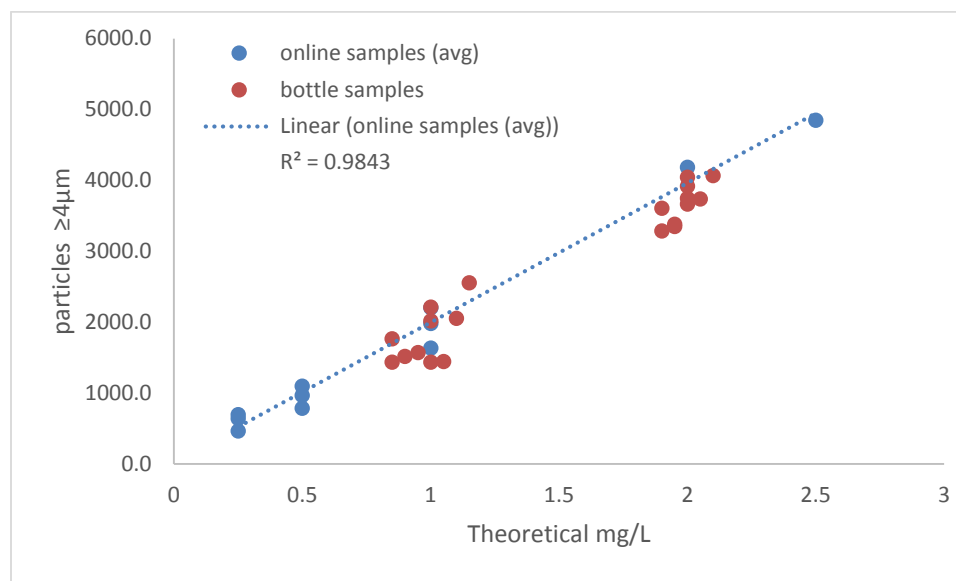


Figure 1. Correlation of total particles $\geq 4\mu\text{m}$ to theoretical concentration (mg/L) of ISO 12103-1 A3 medium test dust.

ISO 12103-1 A2 fine test dust evaluation

ISO 12103-1 A2 fine test dust, having the particle size distribution found in Table 1, has a slight shift from the A3 distribution toward a higher concentration of particles smaller than $10\mu\text{m}$.

The three online evaluations of ISO 12103-1 A2 fine test dust at 1.0 mg/L saw an average of 3355, 3046, and 3059 particles $\geq 4\mu\text{m}$ per milliliter measured via IP 564. The online evaluation for ASTM D7619 averaged 4317 particles $\geq 4\mu\text{m}$ per milliliter for evaluation B. While the ASTM D2276 gravimetric measurements were recorded to be 0.28 mg/L and 0.23 mg/L for evaluation A, 0.47 mg/L and 0.30 mg/L for evaluation B, and 0.68, 0.20, 0.08, 0.65, 0.63 and 0.68 mg/L for evaluation C.

To determine the source of the error between the particle counter measurements and the gravimetric measurements, 11 bottle samples were prepared at TARDEC's Fuels and Petroleum, Oil & Lubricants (POL) Laboratories averaging 2975 particles $\geq 4\mu\text{m}$ per milliliter when measured via IP 564. There was still a variation seen in the gravimetric measurements recorded by ASTM D5452, as was documented in the A3 bottle testing. The particle counting data of the bottle samples was found to be comparable to that seen in online evaluations leading to the conclusion that the EI 1581 injection levels are correct and that the low results from the ASTM D2276 testing is an artifact of that method. The correlation of particle counter data to the theoretical gravimetric concentration, and cross referenced to the bottle sample data, indicates that the collected data is valid Figure 2.

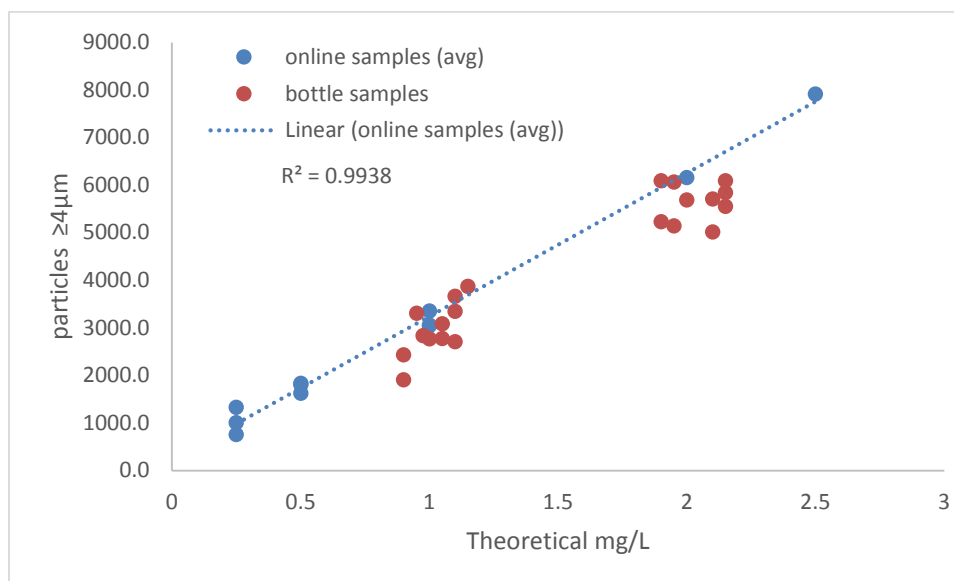


Figure 2. Correlation of total particles $\geq 4\mu\text{m}$ to theoretical concentration (mg/L) of ISO 12103-1 A2 fine test dust.

ISO 12103-1 A1 ultrafine test dust evaluation

ISO 12103-1 A1 ultrafine test dust, having a particle size distribution found in Table 1, is the test dust used in a 90/10 mixture with red iron oxide in the qualification of EI 1581 filters and is composed of 97-100% sub $10\mu\text{m}$ particles.

The three online evaluations of ISO 12103-1 A1 ultrafine test dust at 1.0 mg/L saw an average of 6423, 4882, and 6540 particles $\geq 4\mu\text{m}$ per milliliter measured via IP 564. The online evaluation for ASTM D7619 averaged 5828 particles $\geq 4\mu\text{m}$ per milliliter for evaluation B. While the ASTM D2276 gravimetric measurements were recorded to be 0.28 mg/L and 0.23 mg/L for evaluation A, and 0.35 mg/L and 0.35 mg/L for evaluation B, and 0.05, and 0.80 mg/L for evaluation C.

To determine the source of the error between the particle counter measurements and the gravimetric measurements, 10 bottle samples were prepared at TARDEC's Fuels and Petroleum, Oil & Lubricants (POL) Laboratories averaging 6135 particles $\geq 4\mu\text{m}$ per milliliter when measured via IP 564. Variation was seen in the gravimetric measurements recorded by ASTM D5452, as was documented in the previous bottle testing. The particle counting data of the bottle samples was found to be comparable to that seen in online evaluations leading to the conclusion that the EI 1581 injection levels are correct and that the low results from the ASTM D2276 testing is an artifact of that method. The correlation of particle counter data to the theoretical gravimetric concentration, and cross referenced to the bottle sample data, indicates that the collected data is valid Figure 3.

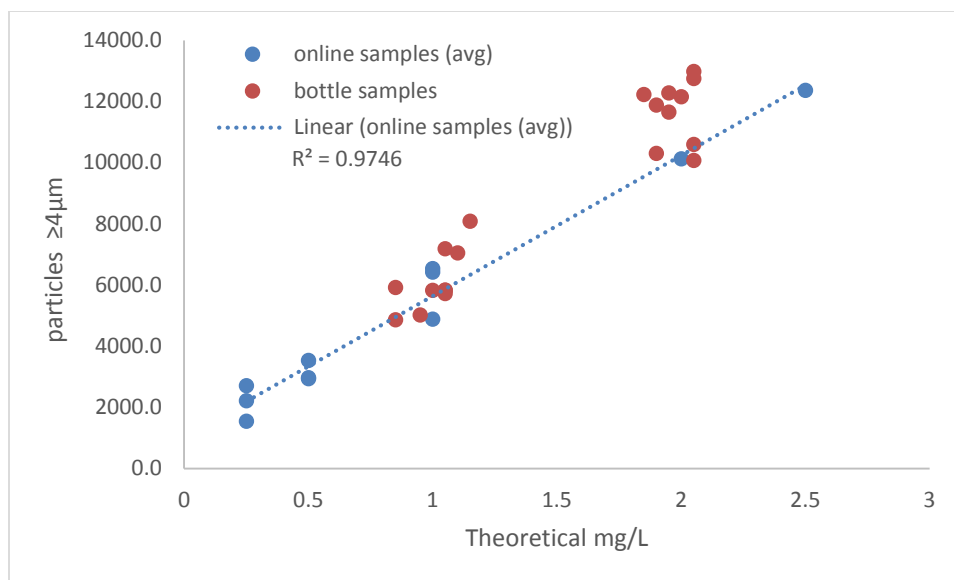


Figure 3. Correlation of total particles $\geq 4\mu\text{m}$ to theoretical concentration (mg/L) of ISO 12103-1 A2 fine test dust.

Red Iron Oxide test dust evaluation

Red Iron Oxide test dust, having a particle size distribution composed of sub $10\mu\text{m}$ particles similar to that of ISO 12103-1 A1 ultrafine test dust is detailed in Table 1.

The three online evaluations of red iron oxide test dust at 1.0 mg/L saw an average of 18925, and 21173, particles $\geq 4\mu\text{m}$ per milliliter measured via IP 564 for evaluation a and b respectively, while evaluation c saw 6741 particles $\geq 4\mu\text{m}$ per milliliter measured via IP 564. The variation seen in evaluation c from what was seen in evaluations a and b is unknown. The online evaluation for ASTM D7619 averaged 35430 particles $\geq 4\mu\text{m}$ per milliliter for evaluation B. The gravimetric measurements per ASTM D2276 were recorded to be 0.27 mg/L and 0.20 mg/L for evaluation a, and 0.92 mg/L and 0.74 mg/L for evaluation b, and 0.30, and 0.43 mg/L for evaluation c, a variation that does not lineup with the variation seen in the particle counts.

Free water evaluation

The three free water evaluations provided similar to what was seen with the red iron oxide results with evaluation c providing results lower than were seen for evaluations a and b. Free water in excess of 5 ppm contains water droplets, $\geq 4\mu\text{m}$, and exceeding 4000 in counts per milliliter. The distribution of the free water across the droplet size measurements of the light obscuration particle counts showed that 35% of the water droplets were between 4-6 μm , 55% between 6-14 μm , 9.5% between 14-30 μm , and 0.5% greater than 30 μm in size. This allows an operator to determine the possibility of water contamination by looking at the distribution of particles/droplets identified by the particle counter. If water contamination is suspected, particle counts should be rerun with co-solvent (Resolver[®] or isopropyl alcohol) to remove the effect of water on particle counts and ASTM D3240 run to determine the level of water contamination.

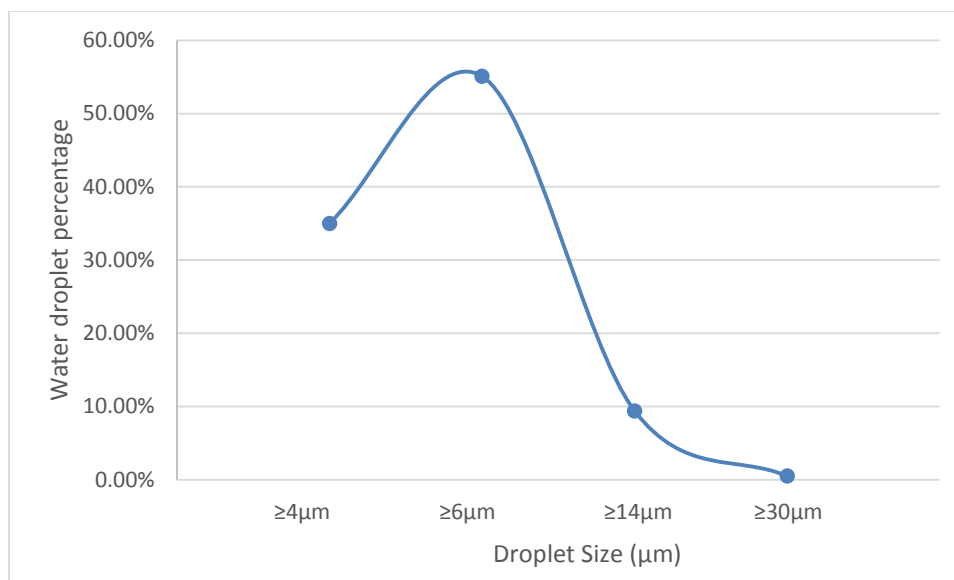


Figure 4. Water Droplet Distribution.

Test dust and free water test dust evaluation

The major drawback to light obscuration particle counting is that the technology is unable to differentiate between solid particulate contamination and free water droplets. During the course of the three online evaluations free water was injected in the presence of A1 test dust, A2 test dust, A3 test dust, and Red Iron Oxide. These evaluations were performed by injecting water into the fuel immediately following the standard test dust evaluations, the particle counts of the water droplets are additive to the particulate particle counts, as shown in Appendix E.

Conclusions

The laboratory data contained in this report was used to ISO code limits of 19/17/14/13, based on the 1.0 mg/L concentration levels for the A2 test dust, and down to a 5 ppm free water presence. Although a direct correlation between the light obscuration particle counters and gravimetric method cannot be established across all test dusts tested, the limits based around A2 test dust reduces the amount smaller contaminants, A1 and RIO test dust. The utilization of ISO code groupings does reduce the depth of information available from the particle count measurements, but does provide a sound basis for comparison multiple particle counters, and the calibration variation allowed within ISO-11171, back to gravimetric measurements. Both light obscuration particle counter technologies evaluated were able to properly measure solid particulate contamination and provide an indication of the presence of free water down to the 5 ppm level.

References

1. **Department of Defense Standard Practice.** Quality Assurance/Surveillance for Fuels, Lubricants and Related Products. *MIL-STD-3004D*. October 9, 2014.
2. **Headquarters Department of the Army.** Petroleum Supply Operations. *Army Techniques Publication 4-43*. Washington DC : s.n., August 06, 2015. ATP 4-43.
3. **Schmitigal, J., Cox, D., Boenker, M., Krizovensky, J.O.** Update on the US Army's Fuel Contamination Detection Efforts. Seattle, Washington : Coordinating Research Council, Inc. 2011 Aviation Technical Committee Meetings, May 2011.
4. **Besse, G., Schmitigal, J.** Army's Evaluation of Aviation Fuel Contaminants Using Electronic Sensors. Alexandria VA : Coordinating Research Council, Inc. Vols. 2013 Aviation Technical Committee Meetings, May 2012.
5. **Headquarters Department of the Army.** Inventory Management Supply Policy Below the National Level. *Army Regulation 710-2*. Washington DC : s.n., March 28, 2008.
6. **Energy Institute.** Design, functional requirements and laboratory testing protocols for electronic sensors to monitor free water and/or particulate matter in aviation fuel. 2nd London : Energy Institute, February 2012.
7. —. Handbook on electronic sensors for the detection of particulate matter and/or free water during aircraft refuelling. 1st London, UK : Energy Institute, August 2012.
8. **Hydraulic fluid power — Calibration of automatic particle counters for liquids.** Geneva : International Organization for Standardization. ISO 11171:2010(E).
9. **Hydraulic fluid power — Fluids — Method for coding the level of contamination by solid particles.** Geneva : International Organization for Standardization. ISO 4406:1999(E).
10. **Determination of the level of cleanliness of aviation turbine fuel – Laboratory automatic particle counter method.** IP 564/13.
11. **Determination of the level of cleanliness of aviation turbine fuel – Portable automatic particle counter method.** IP 565/13.
12. **Determination of the level of cleanliness of aviation turbine fuel – Automatic particle counter method using light extinction.** IP 577/13.
13. **Standard Test Method for Sizing and Counting Particles in Light and Middle Distillate Fuels, by Automatic Particle Counter.** West Conshohocken, PA : ASTM International, December 1, 2012. ASTM D7619-12b.
14. **Department of Defense.** General Specification for Engines, Aircraft, Turbojet and Turbofan. *Military Specification*. October 15, 1973. MIL-E-5007D.

List of Symbols, Abbreviations, and Acronyms

μm	Micrometer
ASTM	ASTM International
CCR	Closed Circuit Refueling
DLA-E	Defense Logistics Agency Energy
EI	Energy Institute
IOS	icountOS
ISO	International Organization for Standardization
m	Minutes
mg/L	Milligrams per Liter
MIL	Military
mL	Milliliter
POL	Petroleum Oil Lubricants
PPM	Parts Per Million
s	Seconds
STD	Standard
TARDEC	Tank Automotive Research Development and Engineering Center
U.S.	United States

Appendix A Online Evaluation 1

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A3 1.0 mg/L	0		0.4	2094.3	736.6	28.2	6.3	2.4	0.7	18	17	12	7
	3			2034.5	707.8	27.1	5.6	2.9	0.7	18	17	12	7
	5	0.25		1984.3	709.1	24.1	5.1	2.1	0.6	18	17	12	6
	7			1982.7	700.4	25.6	6.4	2.4	0.9	18	17	12	7
	11			1954.4	682.6	25.9	6.7	3.3	1.2	18	17	12	7
	13			1936.2	690.1	26.9	7.0	3.2	0.9	18	17	12	7
	15	0.27		1934.8	676.3	25.9	6.4	3.1	1.0	18	17	12	7
	23			1952.1	692.3	23.9	5.2	2.1	0.5	18	17	12	6

Table A 1 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A3 0.5 mg/L	0		0.4	971.1	334.9	11.6	3.1	1.5	0.3	17	16	11	5
	5	0.80		974.8	326.4	10.6	2.6	1.3	0.4	17	16	11	6
	7			955.5	320.4	10.1	2.0	0.9	0.4	17	16	11	6
	9			974.9	330.6	11.4	2.4	1.5	0.2	17	16	11	5
	13			984.1	335.9	11.1	2.1	0.8	0.1	17	16	11	4
	15			945.1	315.6	11.1	1.9	0.6	0.3	17	15	11	5
	16	0.10		965.9	324.0	11.8	2.0	1.4	0.3	17	16	11	5

Table A 2 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A3 0.25 mg/L	0		0.4	710.0	228.5	7.6	1.4	0.6	0.3	17	15	10	5
	2			672.5	223.1	7.2	1.6	1.1	0.1	17	15	10	4
	3			653.7	212.3	6.8	1.1	0.3	0.1	17	15	10	4
	7	0.08		702.4	225.5	7.6	1.4	0.9	0.4	17	15	10	6
	9			710.1	232.6	7.3	1.3	0.9	0.3	17	15	10	5
	11			686.9	219.6	7.1	1.3	0.4	0.1	17	15	10	4
	16			716.6	232.1	6.9	1.4	0.6	0.4	17	15	10	6
	20	0.10		671.9	210.9	5.7	1.1	0.6	0.2	17	15	10	5
	22			676.1	213.4	5.9	1.1	0.3	0.0	17	15	10	0
	26			731.6	232.3	6.1	1.2	0.3	0.0	17	15	10	0
	27			737.0	244.7	7.8	1.6	0.6	0.3	17	15	10	5

Table A 3 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A2 1.0 mg/L	0		0.6	3480.0	855.8	20.0	5.4	2.8	0.7	19	17	11	7
	1			3393.1	844.1	22.6	6.7	3.5	0.6	19	17	12	6
	3	0.28		3374.9	820.3	20.9	5.7	2.5	0.9	19	17	12	7
	7			3293.4	814.5	21.6	5.1	2.3	0.9	19	17	12	7
	9			3330.2	820.4	22.6	5.8	2.6	0.4	19	17	12	6
	12			3325.2	822.6	20.0	5.6	2.4	0.9	19	17	11	7
	18	0.23		3309.8	818.4	20.6	5.8	2.9	0.6	19	17	12	6
	21			3358.6	813.1	20.0	5.8	2.8	0.6	19	17	11	6
	22			3334.4	816.2	20.1	4.6	2.1	0.6	19	17	12	6

Table A 4 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A2 0.5 mg/L	0		0.6	1826.0	445.4	10.8	2.2	1.4	0.4	18	16	11	6
	2			1801.2	433.6	10.5	2.3	1.4	0.2	18	16	11	5
	4	0.13		1841.4	456.3	11.1	2.5	1.6	0.4	18	16	11	6
	16			1787.7	429.5	13.1	4.1	1.8	0.4	18	16	11	6
	18			1821.4	437.7	11.7	3.2	1.1	0.3	18	16	11	5
	20	0.13		1779.8	423.6	11.8	2.3	0.9	0.1	18	16	11	4

Table A 5 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A2 0.25 mg/L	0		0.6	1324.2	309.5	5.9	1.4	0.6	0.2	18	15	10	5
	3	0.08		1359.9	324.6	6.1	1.6	0.6	0.1	18	16	10	4
	5	0.13		1304.4	307.1	7.4	1.6	0.6	0.0	18	15	10	0
A2 0.25 mg/L - 8.8ppm water	0		8.0	7393.2	3655.5	325.4	92.9	36.9	6.1	20	19	16	10
	3		7.2	7215.8	3543.5	318.9	93.0	34.5	5.6	20	19	15	10
A2 0.25 mg/L - 8.8ppm water	0		8.8	9057.1	4791.2	451.4	129.4	50.7	7.9	20	19	16	10
	2			8844.6	4634.7	433.9	124.3	48.8	7.5	20	19	16	10
A2 0.25 mg/L - 33.6 ppm water	0		33.9	26813.1	17067.6	2095.9	596.9	244.2	40.0	22	21	18	12
	3		33.3	26501.2	16958.1	2104.3	621.9	255.1	39.1	22	21	18	12
	6			26347.5	16840.0	2044.5	601.2	241.4	38.9	22	21	18	12

Table A 6 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A1 1.0 mg/L	0		0.6	6382.8	1884.1	5.2	0.6	0.3	0.0	20	18	10	0
	4	0.28		6184.2	1833.6	4.6	0.2	0.2	0.0	20	18	9	0
	6			6470.7	1889.4	4.3	0.4	0.1	0.0	20	18	9	0
	10			6431.7	1880.9	5.1	1.0	0.3	0.0	20	18	10	0
	12			6498.2	1901.0	4.1	0.1	0.1	0.0	20	18	9	0
	15			6473.9	1890.4	3.7	0.3	0.1	0.0	20	18	9	0
	19	0.13		6481.4	1915.7	3.0	0.1	0.0	0.0	20	18	9	0
	22			6485.3	1921.7	6.4	1.1	0.4	0.1	20	18	10	4
	24			6402.1	1901.5	3.9	0.6	0.3	0.1	20	18	9	4

Table A 7 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A1 0.5 mg/L	0		0.6	3493.3	993.4	2.1	0.3	0.2	0.1	19	17	8	4
	2			3581.2	1022.6	2.9	0.3	0.2	0.0	19	17	9	0
	4	0.05		3709.9	1073.9	4.1	0.8	0.3	0.0	19	17	9	0
	12			3549.5	1015.5	2.6	0.2	0.0	0.0	19	17	9	0
	13			3506.0	991.2	2.3	0.6	0.3	0.1	19	17	8	4
	15			3472.9	975.4	2.4	0.1	0.1	0.1	19	17	8	4
	19	0.13		3565.2	1018.7	5.1	1.0	0.4	0.0	19	17	10	0
	21			3446.3	981.5	3.5	0.5	0.3	0.1	19	17	9	4
	23			3468.8	978.1	2.9	0.4	0.0	0.0	19	17	9	0

Table A 8 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A1 0.25 mg/L	0		0.6	2637.1	725.9	2.5	0.1	0.0	0.0	19	17	8	0
	2			2800.1	779.8	3.3	0.6	0.4	0.1	19	17	9	4
	5	0.15		2781.2	754.9	1.9	0.1	0.1	0.0	19	17	8	0
	9			2640.6	744.1	1.6	0.4	0.1	0.0	19	17	8	0
	11			2788.3	761.4	2.1	0.4	0.1	0.0	19	17	8	0
	13			2725.3	746.4	2.6	0.4	0.2	0.0	19	17	9	0
	17			2665.1	739.3	2.4	0.5	0.1	0.0	19	17	8	0
	19	0.10		2721.3	745.1	1.9	0.1	0.1	0.0	19	17	8	0
	21			2614.4	707.1	1.7	0.2	0.1	0.0	19	17	8	0

Table A 9 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
RIO 1.0 mg/L	0		0.7	18805.1	3723.9	8.9	1.4	0.3	0.0	21	19	10	0
	7	0.27		18769.6	3704.4	8.4	0.9	0.2	0.0	21	19	10	0
	9			18903.0	3790.9	9.7	1.2	0.4	0.1	21	19	10	4
	11			18768.1	3707.9	6.7	0.2	0.0	0.0	21	19	10	0
	15			18845.2	3763.6	9.0	0.9	0.4	0.0	21	19	10	0
	17	0.20		18957.4	3757.1	8.1	0.9	0.4	0.0	21	19	10	0
	23			19426.1	3900.9	9.1	1.2	0.4	0.1	21	19	10	4

Table A 10 – Evaluation 1 IP 564 particle count data for red iron oxide test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
RIO 0.5 mg/L	0		0.7	10719.7	1642.3	2.2	0.5	0.1	0.0	21	18	8	0
	2			10952.2	1719.1	3.6	0.4	0.1	0.0	21	18	9	0
	4	0.18		11269.6	1787.7	4.6	0.6	0.1	0.0	21	18	9	0
	10			11438.6	1769.1	5.4	0.6	0.1	0.0	21	18	10	0
	12			11394.8	1755.3	3.4	0.1	0.0	0.0	21	18	9	0
	14			11212.9	1686.4	4.6	0.7	0.3	0.0	21	18	9	0
	17			11903.1	1859.9	3.8	0.2	0.1	0.0	21	18	9	0
	19	0.20		11647.0	1747.1	3.1	0.1	0.0	0.0	21	18	9	0
	21			11467.1	1725.1	3.9	0.2	0.1	0.0	21	18	9	0

Table A 11 – Evaluation 1 IP 564 particle count data for red iron oxide test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
RIO 0.25 mg/L	0		0.7	9304.4	1285.5	3.1	0.4	0.1	0.1	20	17	9	4
	2			8908.9	1236.1	8.3	1.9	0.9	0.1	20	17	10	4
	4	0.15		8548.0	1093.1	1.8	0.3	0.1	0.0	20	17	8	0
	8			9146.1	1224.4	2.3	0.4	0.1	0.0	20	17	8	0
	11			8693.1	1110.2	4.0	0.6	0.4	0.1	20	17	9	4
	13	0.17		8774.1	1125.9	2.1	0.4	0.3	0.2	20	17	8	5

Table A 12 – Evaluation 1 IP 564 particle count data for red iron oxide test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
0.25 mg/L RIO - 5 ppm H2O	0			11887.4	3498.7	247.6	69.7	27.5	4.8	21	19	15	9
	3			11324.7	3216.9	229.3	70.4	27.2	3.8	21	19	15	9
	4			11422.4	3282.5	234.1	67.4	26.0	4.3	21	19	15	9
Open RIO/ 5 ppm H2O	0			39532.8	12298.9	294.9	74.9	29.5	3.9	22	21	15	9
	2			42851.1	14078.9	300.4	73.7	29.5	4.4	23	21	15	9
	4			34560.5	11283.9	282.1	71.5	26.9	4.1	22	21	15	9

Table A 13 – Evaluation 1 IP 564 particle count data for red iron oxide test dust with free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
5.6 ppm H2O	0			5016.8	3179.1	319.7	92.3	37.1	6.4	20	19	15	10
	3			5017.9	3193.4	316.1	89.0	34.3	5.1	20	19	15	10
	5		6.9	5234.5	3352.1	330.9	94.0	34.4	5.4	20	19	16	10
	8			3788.2	2389.0	233.1	65.1	26.6	4.1	19	18	15	9
	11		6.7	3888.9	2464.4	237.0	67.1	26.9	4.5	19	18	15	9
	13			3906.9	2467.9	245.5	70.4	27.8	5.1	19	18	15	10
	17		4.1	3968.4	2507.8	256.3	74.3	29.9	4.9	19	19	15	9
	19		5.0	3787.9	2402.1	239.6	70.6	28.9	5.4	19	18	15	10
	20		5.1	3748.4	2374.6	234.9	67.4	26.7	5.5	19	18	15	10

Table A 14 – Evaluation 1 IP 564 particle count data for 5 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
7.1 ppm H2O	0			7092.1	4558.0	426.5	119.9	47.4	6.7	20	19	16	10
	2		6.7	6329.4	4101.3	403.5	119.8	44.9	6.5	20	19	16	10
	4			6794.2	4407.1	442.7	127.1	50.1	7.4	20	19	16	10
	8		7.2	6898.7	4420.4	444.6	129.4	47.8	7.2	20	19	16	10
	11			6824.3	4368.7	440.9	120.5	47.9	7.4	20	19	16	10
	13		8.1	7020.2	4491.9	455.1	126.5	46.1	7.0	20	19	16	10
	18		7.5	6731.4	4308.1	437.3	127.5	48.6	8.6	20	19	16	10
	23			6871.2	4395.3	445.2	135.6	51.1	8.0	20	19	16	10
	25		6.2	6937.2	4431.4	477.6	139.2	55.9	8.8	20	19	16	10

Table A 15 – Evaluation 1 IP 564 particle count data for 7 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
12.6 ppm H2O	0		12.9	8943.7	5781.1	597.8	171.7	67.8	10.6	20	20	16	11
	2			8949.1	5800.6	618.1	180.6	72.0	12.4	20	20	16	11
	6		8.2	9001.9	5811.6	600.1	172.6	68.8	12.2	20	20	16	11
	10		12.4	9076.8	5849.5	617.5	175.4	70.7	10.0	20	20	16	10
	12		12.3	9134.7	5905.6	597.9	173.4	66.3	10.1	20	20	16	11
	14		12.9	9245.1	5955.2	629.5	182.1	71.6	10.5	20	20	16	11

Table A 16 – Evaluation 1 IP 564 particle count data for 12 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
16.2 ppm H2O	0			11188.2	7284.1	801.3	240.7	97.5	15.6	21	20	17	11
	5		16.9	11011.4	7157.4	766.9	222.4	87.8	16.6	21	20	17	11
	9		17.2	11286.5	7325.6	800.3	230.4	91.4	16.2	21	20	17	11
	13			11121.5	7190.1	764.6	224.9	86.2	14.4	21	20	17	11
	15		14.5	10890.4	7068.4	756.9	215.9	82.2	13.3	21	20	17	11
	17		16.1	11212.4	7296.6	786.5	223.6	89.8	14.0	21	20	17	11

Table A 17 – Evaluation 1 IP 564 particle count data for 15 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
40 ppm H2O	0		39.6	27380.7	18466.9	2325.0	668.9	267.4	41.8	22	21	18	13
	2			26435.7	17863.6	2243.2	648.6	259.2	40.4	22	21	18	13
	4		40.7	28121.3	19040.8	2480.6	733.4	300.3	48.6	22	21	18	13
	8		39.9	26581.9	17996.9	2329.4	684.1	286.0	45.4	22	21	18	13
	11		40.6	26790.7	18139.6	2328.1	698.2	286.3	45.8	22	21	18	13
	15		38.2	26919.8	18277.4	2379.4	714.1	295.5	47.8	22	21	18	13

Table A 18 – Evaluation 1 IP 564 particle count data for 40 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
water slug	0		very high	92109.8	82643.0	52232.5	35679.5	26705.0	13332.8	24	24	23	21
	3			92434.9	82902.8	52303.0	35663.7	26660.0	13218.9	24	24	23	21

Table A 19 – Evaluation 1 IP 564 particle count data for water slug test.

Appendix B Online Evaluation 2

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A3 2.5 mg/L	5	1.0750	0.2	5090.3	1779.3	108.2	24.7	10.0	3.6	20	18	14	9	6340.9	2441.1	97.5	10.6	2.5	0.5	20	18	14	6
	10			4767.2	1632.4	84.8	17.9	7.9	2.5	19	18	14	8	6185.3	2378.0	95.7	11.3	2.7	0.7	20	18	14	7
	15			5047.4	1796.5	118.1	27.5	12.5	4.9	20	18	14	9	6121.1	2335.8	93.2	11.0	2.5	0.5	20	18	14	6
	20	1.4525		4695.9	1595.0	92.9	17.1	6.7	2.4	19	18	14	8	6123.4	2342.1	93.7	11.3	2.9	0.5	20	18	14	6
	25			4765.8	1652.4	98.0	21.9	9.9	3.1	19	18	14	9	6127.2	2333.6	93.9	10.8	2.7	0.5	20	18	14	6
	30			4716.5	1623.2	94.1	20.1	8.2	2.9	19	18	14	9	6087.0	2319.3	93.2	10.4	2.2	0.5	20	18	14	6

Table B 1 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A3 medium test dust at 2.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
2.5 mg/L + Water				8448.1	3773.1	292.6	63.5	23.7	6.6	20	19	15	10

Table B 2 - Evaluation 2 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 2.5 mg/L concentration with free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A3 2.0 mg/L	5	1.0925	0.2	4219.8	1501.0	97.6	21.7	10.3	4.2	19	18	14	9	4990.1	1986.5	90.1	11.7	3.5	1.1	19	18	14	7
	10			4116.9	1430.1	85.7	17.6	8.6	3.1	19	18	14	9	5065.1	2049.3	105.5	15.1	4.8	1.4	20	18	14	8
	15			4142.6	1458.1	81.6	17.0	8.0	3.0	19	18	14	9	5168.7	2115.2	128.3	20.5	6.8	2.1	20	18	14	8
	20	1.0775		4644.9	1735.9	115.6	27.6	12.6	5.3	19	18	14	10	5266.0	2176.3	143.3	23.5	8.6	3.0	20	18	14	9
	25			4019.4	1402.3	86.2	20.3	8.9	3.0	19	18	14	9	5046.3	1964.8	85.9	10.8	3.1	1.0	20	18	14	7
	30			3976.0	1381.0	81.2	16.8	8.0	2.7	19	18	14	9	5008.1	1936.2	84.2	11.3	3.1	0.7	20	18	14	7

Table B 3 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A3 medium test dust at 2.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A3 1.0 mg/L	5	0.1550	0.2	2098.0	743.3	34.7	7.3	3.5	1.2	18	17	12	7	2546.9	1077.2	50.9	7.5	1.8	0.4	19	17	13	6
	10			2155.1	764.5	33.1	6.1	3.3	1.3	18	17	12	7	2588.3	1099.5	55.0	7.1	2.0	0.6	19	17	13	6
	15			2251.4	816.1	44.9	10.4	4.2	1.8	18	17	13	8	2640.9	1126.5	63.5	9.4	3.1	0.9	19	17	13	7
	20	0.3325		2242.5	801.1	42.3	8.9	2.8	0.6	18	17	13	6	2636.5	1116.9	59.4	8.5	2.4	0.9	19	17	13	7
	25			2359.5	854.3	52.0	12.8	5.4	1.8	18	17	13	8	2657.1	1142.5	63.7	10.8	3.2	0.8	19	17	13	7
	30			2125.4	749.7	42.0	7.8	3.0	1.0	18	17	13	7	2576.6	1075.0	52.0	6.9	1.7	0.6	19	17	13	6

Table B 4 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A3 medium test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A3 0.50 mg/L	5	0.1800		1107.1	372.0	20.5	4.4	2.1	0.5	17	16	12	6	1332.6	513.5	26.1	4.4	1.3	0.4	18	16	12	6
	10			1121.0	372.9	21.4	3.9	1.6	0.4	17	16	12	6	1317.8	501.8	23.6	3.7	1.1	0.3	18	16	12	5
	15			1077.4	354.1	19.6	4.3	2.2	0.9	17	16	11	7	1319.3	491.0	21.5	3.2	1.1	0.3	18	16	12	5
	20			1090.5	365.6	19.3	4.9	1.9	0.9	17	16	11	7	1350.4	520.2	25.9	4.5	1.7	0.6	18	16	12	6
	25	0.1975	0.2	1099.9	365.7	16.7	3.1	1.6	0.8	17	16	11	7	1328.3	504.3	21.0	3.3	1.0	0.4	18	16	12	6
	30			1096.1	363.0	20.0	4.2	1.4	0.4	17	16	11	6	1324.1	493.2	23.3	3.4	1.0	0.4	18	16	12	6

Table B 5 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A3 medium test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A3 0.25 mg/L	5	0.1000		657.1	221.0	12.7	3.2	1.7	0.4	17	15	11	6	776.4	301.5	16.2	3.0	1.2	0.5	17	15	11	6
	10			646.1	215.4	10.7	2.1	0.9	0.4	17	15	11	6	757.2	286.0	13.3	2.4	0.9	0.3	17	15	11	5
	15			630.9	211.9	12.3	2.9	1.5	0.9	16	15	11	7	738.0	280.3	15.1	2.9	0.8	0.4	17	15	11	6
	20	0.0750	0.1	646.4	212.1	12.4	2.5	1.1	0.4	17	15	11	6	740.9	286.6	15.1	2.4	0.6	0.4	17	15	11	6
	25			659.6	225.6	12.9	3.1	1.6	0.8	17	15	11	7	735.4	280.1	13.8	2.3	1.1	0.3	17	15	11	5
	30			605.6	203.6	10.4	2.6	1.1	0.1	16	15	11	4	721.5	270.5	11.4	1.8	0.6	0.2	17	15	11	5

Table B 6 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A3 medium test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A2 2.5 mg/L	5	0.9375		7746.1	1934.2	79.5	19.9	9.7	3.6	20	18	13	9	11638.8	3491.3	67.2	6.0	1.2	1.0	21	19	13	7
	10		0.3	7397.8	1784.5	62.9	15.5	6.9	2.4	20	18	13	8	11219.2	3376.6	67.1	7.4	1.6	0.3	21	19	13	5
	15	0.8125		7207.1	1693.5	51.7	10.9	4.3	1.1	20	18	13	7	11133.0	3349.8	64.0	6.7	1.7	0.3	21	19	13	5
	20			9298.9	2974.2	356.5	146.1	87.1	39.9	20	19	16	12	11047.4	3303.4	62.1	6.6	1.7	0.5	21	19	13	6

Table B 7 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A2 fine test dust at 2.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A2 2.0 mg/L	5	0.1075		6095.7	1443.9	48.6	11.8	5.7	1.6	20	18	13	8	9043.2	2792.3	52.6	5.9	1.2	0.3	20	19	13	5
	10		0.2	6385.9	1656.0	88.0	26.1	13.4	6.5	20	18	14	10	9050.1	2771.4	51.5	5.8	1.1	0.2	20	19	13	5
	15	1.1525		6214.6	1547.1	71.8	21.2	11.2	4.7	20	18	13	9	9022.0	2771.6	50.4	5.5	1.2	0.2	20	19	13	5
	20			5932.4	1411.5	48.3	11.2	4.8	0.9	20	18	13	7	8993.0	2766.1	51.6	5.1	1.3	0.2	20	19	13	5

Table B 8 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A2 fine test dust at 2.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A2 1.0 mg/L	5	0.4700		3152.5	771.2	26.1	6.7	3.2	1.7	19	17	12	8	4453.0	1452.0	26.4	3.0	0.8	0.1	19	18	12	4
	10		0.3	2978.6	727.1	23.0	6.8	3.1	0.6	19	17	12	6	4294.7	1393.4	27.6	2.7	0.8	0.3	19	18	12	5
	15	0.3000		3080.9	769.6	31.7	8.1	3.9	1.5	19	17	12	8	4253.2	1381.6	26.6	3.0	0.7	0.3	19	18	12	5
	20			2971.8	714.6	26.5	5.9	2.6	1.2	19	17	12	7	4269.5	1376.2	25.3	2.6	0.7	0.2	19	18	12	5

Table B 9 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A2 fine test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A2 0.50 mg/L	5	0.1075		1760.6	404.8	16.9	4.0	1.9	0.9	18	16	11	7	2536.6	766.6	15.1	2.4	0.4	0.1	19	17	11	4
	10		0.4	1764.7	403.1	15.9	3.8	1.5	0.3	18	16	11	5	2542.0	773.6	16.8	2.4	0.8	0.3	19	17	11	5
	15	0.3500		1729.6	388.0	13.6	3.2	1.3	0.4	18	16	11	6	2548.8	777.2	16.8	2.8	0.5	0.2	19	17	11	5
	20			2090.6	556.2	46.4	17.0	8.9	4.6	18	16	13	9	2564.6	776.0	17.1	2.5	1.0	0.3	19	17	11	5

Table B 10 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A2 fine test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A2 0.25 mg/L	5	0.1575		1051.6	259.6	9.9	2.6	1.0	0.5	17	15	10	6	1472.1	476.0	17.1	3.2	1.3	0.5	18	16	11	6
	10		0.3	1061.6	261.8	15.6	5.6	3.1	1.4	17	15	11	8	1412.0	438.2	10.3	1.5	0.5	0.1	18	16	11	4
	15			998.0	232.1	11.0	3.6	1.7	0.9	17	15	11	7	1419.3	434.1	9.3	1.7	0.6	0.2	18	16	10	5
	20	0.1150		986.2	225.9	8.5	2.5	0.9	0.4	17	15	10	6	1408.2	436.0	10.4	1.5	0.4	0.1	18	16	11	4
	25			982.9	223.1	7.8	2.4	0.9	0.2	17	15	10	5	1417.5	429.0	9.8	1.1	0.4	0.2	18	16	10	5
	30			973.9	218.3	6.7	1.4	0.7	0.2	17	15	10	5	1423.7	430.7	9.1	1.6	0.5	0.1	18	16	10	4

Table B 11 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A2 fine test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A1 2.5 mg/L	5	1.1925		13125.7	3933.4	15.7	1.9	0.6	0.1	21	19	11	4	16698.9	7436.8	52.2	2.0	0.5	0.2	21	20	13	5
	10		0.5	12221.6	3642.1	20.5	3.8	1.5	0.7	21	19	12	7	15666.4	6979.2	47.9	1.9	0.5	0.2	21	20	13	5
	15	0.4000		12019.3	3584.8	16.1	3.1	1.8	1.0	21	19	11	7	15714.2	6997.9	49.5	2.0	0.4	0.1	21	20	13	4
	20			12089.4	3589.9	16.8	2.6	1.6	0.6	21	19	11	6	15693.5	6998.1	49.1	2.1	0.4	0.2	21	20	13	5

Table B 12 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 2.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A1 2.0 mg/L	5	0.7775		10237.6	2989.9	18.5	3.7	1.9	0.6	21	19	11	6	12894.0	5767.2	43.7	2.2	0.6	0.4	21	20	13	6
	10		0.6	10202.4	2930.6	22.4	6.0	2.9	1.1	21	19	12	7	12829.4	5740.4	44.0	2.7	0.7	0.3	21	20	13	5
	15	0.7800		10022.6	2885.9	17.6	3.9	1.6	0.5	21	19	11	6	12839.4	5729.0	43.4	2.3	0.6	0.1	21	20	13	4
	20			10061.1	2876.1	18.1	4.6	2.4	1.1	21	19	11	7	12838.6	5721.8	46.5	2.6	0.8	0.3	21	20	13	5

Table B 13 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 2.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A1 1.0 mg/L	5	0.3475		5991.9	1688.6	16.0	4.7	2.9	1.7	20	18	11	8	6843.2	3123.9	24.5	1.6	0.5	0.2	20	19	12	5
	10			4894.5	1354.4	11.4	3.0	1.9	1.0	19	18	11	7	5709.2	2558.3	22.7	1.9	0.4	0.2	20	19	12	5
	15		0.5	4060.9	1119.9	11.7	3.4	1.7	0.8	19	17	11	7	4747.3	2107.7	18.7	2.3	1.2	0.7	19	18	11	7
	20	0.3525		3837.3	1074.7	9.1	2.0	1.0	0.3	19	17	10	5	4643.3	2060.4	18.8	1.6	0.4	0.2	19	18	11	5
	25			4900.9	1377.0	9.9	2.4	0.6	0.3	19	18	10	5	6336.7	2835.8	22.2	1.5	0.3	0.1	20	19	12	4
	30			5604.5	1577.9	10.5	2.9	1.4	0.8	20	18	11	7	6689.3	3003.7	23.7	1.6	0.4	0.2	20	19	12	5

Table B 14 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A1 1.0 mg/L - 10 ppm Water	5		7.9	13091.9	6150.3	455.9	95.5	30.1	8.0	21	20	16	10	13034.4	8307.0	1578.3	397.7	204.3	98.4	21	20	18	14
	10		8.8	13022.9	6208.8	503.4	115.5	36.0	7.8	21	20	16	10	13074.2	8542.9	1704.6	431.1	216.1	104.5	21	20	18	14
	15		8.1	12681.1	6114.9	488.9	107.8	31.2	5.6	21	20	16	10	12302.6	8056.7	1634.5	410.0	204.8	95.5	21	20	18	14
	20			12728.4	6213.1	497.3	104.0	32.6	5.9	21	20	16	10	11766.7	7814.2	1632.8	392.2	194.1	87.8	21	20	18	14

Table B 15 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 1.0 mg/L concentration and 10 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A1 0.50 mg/L	5	0.2150		1666.4	441.7	3.1	0.6	0.3	0.1	18	16	9	4	2090.1	896.0	7.4	1.1	0.5	0.2	18	17	10	5
	10		0.4	3279.4	891.3	5.1	1.4	0.5	0.3	19	17	10	5	4146.2	1767.6	10.9	0.6	0.1	0.1	19	18	11	4
	15			3410.0	979.8	21.8	8.0	4.9	2.4	19	17	12	8	4058.0	1742.6	11.6	0.5	0.2	0.1	19	18	11	4
	20	0.3025		3228.1	875.8	6.6	1.6	1.1	0.5	19	17	10	6	4050.3	1738.6	10.6	0.8	0.3	0.1	19	18	11	4
	25			3136.9	850.9	5.6	1.7	0.9	0.3	19	17	10	5	4025.4	1728.4	10.6	0.4	0.1	0.0	19	18	11	0

Table B 16 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A1 0.25 mg/L	5	0.1075		2243.6	603.8	4.6	1.3	0.6	0.5	18	16	9	6	2847.0	1221.6	7.9	0.4	0.0	0.0	19	17	10	0
	10		0.5	2195.9	598.6	3.9	1.6	1.0	0.6	18	16	9	6	2831.3	1220.4	9.5	0.7	0.2	0.1	19	17	10	4
	15			2209.5	593.8	3.8	0.8	0.4	0.2	18	16	9	5	2794.7	1194.8	7.0	0.7	0.2	0.1	19	17	10	4
	20	0.2400		2192.5	592.5	3.4	0.9	0.6	0.3	18	16	9	5	2777.5	1187.5	7.7	0.1	0.3	0.2	19	17	10	5
	25			2221.0	603.1	3.8	1.1	0.6	0.4	18	16	9	6	2757.3	1174.3	7.2	0.6	0.1	0.1	19	17	10	4

Table B 17 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A1 0.25 mg/L - 5 ppm Water	5		4.0	7918.6	3839.4	266.4	57.3	19.7	5.8	20	19	15	10	6420.1	4399.4	999.7	198.5	86.1	35.1	20	19	17	12
	10		4.0	7753.6	3822.9	247.9	47.5	14.3	2.8	20	19	15	9	5760.1	3952.0	878.4	167.4	73.3	29.0	20	19	17	12
	15		3.8	7108.1	3500.1	233.6	45.5	13.2	2.9	20	19	15	9	5524.0	3762.2	841.0	159.1	71.7	28.7	20	19	17	12
	20		2.3	7082.4	3472.9	229.5	45.3	12.6	2.6	20	19	15	9	5311.7	3554.7	761.6	143.3	61.9	24.5	20	19	17	12
	25		2.7	6478.1	3131.7	203.9	41.1	10.5	2.4	20	19	15	8	4959.7	3258.7	682.0	131.8	59.1	22.4	19	19	17	12
	30		3.3	6083.7	2893.7	180.9	35.1	9.1	1.4	20	19	15	8	4670.3	3011.9	613.4	117.7	51.4	19.8	19	19	16	11

Table B 18 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L concentration with 5 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
RIO 2.5 mg/L	5	1.8225	0.0	39043.4	15495.1	174.1	6.6	1.8	0.4	22	21	15	6	72490.2	23327.3	85.6	5.9	1.5	0.3	23	22	14	5

Table B 19 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for red iron oxide test dust at 2.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
RIO 2.0 mg/L	5			32931.1	8932.7	29.2	3.0	1.1	0.4	22	20	12	6	58791.5	13804.7	37.0	3.0	0.5	0.2	23	21	12	5
	10	2.0750		33154.1	898.1	28.4	2.1	0.9	0.4	22	17	12	6	58612.9	13786.5	34.6	3.0	0.8	0.2	23	21	12	5
	15		0.0	32922.9	8933.7	30.4	2.6	1.3	0.1	22	20	12	4	59234.2	14091.0	35.7	2.7	0.6	0.1	23	21	12	4
	20			33275.6	9160.4	29.6	2.0	0.6	0.2	22	20	12	5										

Table B 20 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for red iron oxide test dust at 2.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
RIO 1.0 mg/L	5	0.9125		23827.6	5060.5	13.6	1.5	0.7	0.2	22	20	11	5	44974.9	10791.7	28.8	2.6	0.3	0.0	23	21	12	0
	10		0.4	20479.8	4042.9	13.2	2.4	1.0	0.4	22	19	11	6	33625.5	8093.5	22.7	2.0	0.4	0.1	22	20	12	4
	15			20467.6	4045.2	11.5	2.0	0.5	0.2	22	19	11	5	32677.2	7814.3	21.7	1.9	0.4	0.0	22	20	12	0
	20	0.7350		20515.9	4062.1	11.7	1.9	0.9	0.6	22	19	11	6	32995.6	8010.4	20.8	1.7	0.5	0.1	22	20	12	4
	25			20572.4	4035.9	13.1	1.8	0.6	0.2	22	19	11	5	32878.6	7938.1	18.4	1.4	0.3	0.1	22	20	11	4

Table B 21 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for red iron oxide test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
RIO 0.50 mg/L	5	0.4075		9839.9	995.6	17.6	2.9	1.1	0.1	20	17	11	4	20121.4	2321.8	37.4	5.6	1.7	0.6	22	18	12	6
	10			9968.0	952.0	13.2	2.5	1.4	0.4	20	17	11	6	20503.4	2301.6	28.3	4.6	1.2	0.4	22	18	12	6
	15			9945.7	938.2	13.5	2.7	0.9	0.3	20	17	11	5	20807.8	2317.5	25.0	3.8	1.8	0.7	22	18	12	7
	20	0.4525	0.3	10925.7	1037.1	15.4	2.6	1.1	0.3	21	17	11	5	21827.1	2380.1	24.8	4.0	1.3	0.3	22	18	12	5
	25			10735.9	1076.1	28.4	8.6	5.0	2.2	21	17	12	8	21527.8	2318.2	20.8	3.5	1.1	0.4	22	18	12	6

Table B 22 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for red iron oxide test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
RIO 0.25 mg/L	5	0.1650		187.6	31.0	1.9	0.3	0.1	0.0	15	12	8		215.2	38.0	3.4	0.5	0.2	0.1	15	12	9	4
	10			6621.1	618.9	10.8	2.0	0.9	0.1	20	16	11	4	14191.6	1541.9	24.2	4.3	1.5	0.5	21	18	12	6
	15			6767.2	640.9	12.8	2.4	1.1	0.6	20	17	11	6	14211.8	1537.4	25.2	3.8	1.2	0.4	21	18	12	6
	20	0.2775	0.4	6700.2	640.8	12.1	2.4	1.1	0.3	20	17	11	5	14152.4	1544.6	25.2	4.5	1.7	0.6	21	18	12	6
	25			6697.5	640.0	11.9	2.0	0.9	0.2	20	16	11	5	14042.1	1552.6	28.3	5.1	1.6	0.6	21	18	12	6

Table B 23 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for red iron oxide test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
5 ppm H2O	5		2.2	3576.1	1986.1	159.0	31.3	10.1	2.2	19	18	14	8	2087.6	1761.0	524.5	114.5	53.8	22.9	18	18	16	12
	10		2.3	3680.4	2003.6	167.5	40.1	12.9	3.9	19	18	15	9	2051.3	1724.4	521.2	115.1	53.2	21.7	18	18	16	12
	15		2.3	4025.4	2227.1	191.6	43.9	13.9	3.0	19	18	15	9	2205.2	1859.5	563.7	121.4	57.9	24.5	18	18	16	12
	20		2.9	4281.1	2383.1	208.4	43.8	12.4	2.3	19	18	15	8	2229.5	1876.4	566.7	120.2	56.0	22.9	18	18	16	12
	25		1.4	4107.0	2281.5	202.5	44.3	12.3	2.6	19	18	15	9	2042.5	1717.3	517.0	109.8	50.6	21.2	18	18	16	12
	30		2.7	4526.8	2511.1	217.5	50.2	15.4	3.4	19	19	15	9	2390.5	2017.1	606.5	131.1	59.5	24.0	18	18	16	12

Table B 24 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for 5 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
10 ppm H2O	5		3.6	5749.7	3222.8	299.1	65.1	20.6	3.9	20	19	15	9	3088.6	2610.7	785.5	172.2	79.1	32.3	19	19	17	12
	10		6.6	8526.3	4836.2	473.4	110.2	33.6	6.1	20	19	16	10	4534.3	3848.7	1145.0	250.0	117.0	46.7	19	19	17	13
	15		8.1	9585.4	5490.1	555.4	130.2	39.6	5.4	20	20	16	10	5226.0	4440.1	1346.9	292.1	135.6	54.5	20	19	18	13
	20		8.2	10814.1	6260.5	640.0	144.5	44.9	6.4	21	20	16	10	6252.8	5312.4	1607.1	345.5	159.5	62.9	20	20	18	13
	25		11.3	11856.1	6849.4	730.4	171.3	53.7	9.8	21	20	17	10	7143.8	6055.1	1833.6	400.3	182.3	76.0	20	20	18	13
	30		10.1	12804.6	7461.9	816.2	185.4	58.1	10.9	21	20	17	11	7225.4	6141.3	1855.1	404.1	183.6	75.4	20	20	18	13

Table B 25 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for 10 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
20 ppm H2O	5		17.7	18462.3	11061.7	1411.4	329.4	106.9	18.5	21	21	18	11	11490.4	9714.8	2933.3	647.5	298.1	120.3	21	20	19	14
	10		19.6	18537.6	11107.8	1415.8	332.1	105.1	15.9	21	21	18	11	11511.2	9743.5	2954.0	656.5	298.4	121.3	21	20	19	14
	15		19.8	18411.8	11036.4	1417.9	327.9	109.1	16.3	21	21	18	11	11566.8	9781.7	2944.3	640.6	292.2	118.7	21	20	19	14
	20		18.9	18900.7	11321.4	1451.8	339.5	110.7	17.4	21	21	18	11	11826.4	10008.9	3017.3	663.0	298.9	121.6	21	21	19	14

Table B 26 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for 20 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
30 ppm H2O	5		25.0	25139.6	15661.3	2468.2	608.4	211.9	37.7	22	21	18	12	17842.0	15079.2	4595.3	1017.6	461.9	187.6	21	21	19	15
	10		27.5	25426.1	15850.9	2458.0	619.9	207.5	34.9	22	21	18	12	17881.6	15089.7	4569.6	1013.4	463.0	184.0	21	21	19	15
	15		27.7	25175.5	15689.9	2507.9	626.2	217.2	40.1	22	21	19	13	18574.4	15661.2	4747.3	1064.0	479.2	192.7	21	21	19	15
	20		24.4	25413.9	15848.2	2473.1	612.3	203.6	35.7	22	21	18	12	18281.7	15397.3	4652.0	1031.5	473.2	185.1	21	21	19	15

Table B 27 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for 30 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
40 ppm H2O	5		34.7	29188.0	18752.6	3440.3	897.7	326.7	59.3	22	21	19	13	23894.2	20166.8	6186.7	1406.0	635.4	255.0	22	22	20	15
	10		34.9	30836.9	19972.9	3783.4	994.1	357.5	62.8	22	21	19	13	25539.7	21497.3	6547.9	1499.4	682.1	275.5	22	22	20	15
	15		37.2	31111.9	20283.0	4043.0	1083.9	391.6	71.4	22	22	19	13	26683.8	22424.2	6816.4	1563.0	701.5	284.5	22	22	20	15
	20		37.6	21638.9	20652.4	4056.0	1073.8	387.9	65.8	22	22	19	13	27709.7	23230.6	7069.8	1632.8	739.2	300.5	22	22	20	15

Table B 28 - Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for 40 ppm free water.

Appendix C Online Evaluation 3

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A3 1.0 mg/L	5	0.2		1784.3	586.7	28.6	6.4	2.3	0.9	18	16	12	7
	10			1650.9	547.1	24.6	4.6	1.4	0.4	18	16	12	6
	15		0.6	1614.9	535.6	30.0	5.6	2.6	0.9	18	16	12	7
	25	0.5		1606.2	540.2	28.2	5.6	2.4	0.9	18	16	12	7
	30			1610.9	540.9	30.6	5.9	2.6	1.1	18	16	12	7
	35			1603.9	541.6	26.6	5.4	2.3	1.0	18	16	12	7
	40			1625.0	541.2	31.2	6.1	2.8	1.2	18	16	12	7
	45			1589.0	525.2	24.1	4.3	1.7	0.4	18	16	12	6

Table C 1 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A3 0.5 mg/L	5	0.25		548.2	176.8	8.9	1.4	0.2	0.1	16	15	10	4
	10			838.9	268.3	13.4	2.4	1.2	0.6	17	15	11	6
	15		0.9	833.1	276.1	13.3	2.6	1.1	0.3	17	15	11	5
	20	0.075		819.2	261.8	12.0	2.4	1.0	0.4	17	15	11	6
	25			849.7	273.8	11.9	2.4	1.1	0.3	17	15	11	5
	30			842.9	268.7	12.1	1.9	0.9	0.4	17	15	11	6

Table C 2 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A3 0.25 mg/L	5	0.15		464.5	144.7	5.6	1.0	0.3	0.1	16	14	10	4
	10			453.1	137.1	6.3	1.2	0.4	0.1	16	14	10	4
	15		0.8	438.4	137.4	6.4	0.9	0.2	0.1	16	14	10	4
	20	0.2		479.6	149.9	6.9	1.1	0.4	0.2	16	14	10	5
	25			476.9	145.7	5.9	0.6	0.3	0.0	16	14	10	0
	30			486.0	153.2	6.9	1.6	0.6	0.1	16	14	10	4

Table C 3 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A2 1.0 mg/L	5	0.68		3116.7	665.6	28.1	7.2	3.2	0.9	19	17	12	7
	10	0.20		2984.1	637.9	22.9	6.0	3.1	0.4	19	16	12	6
	15	0.08		3013.9	643.1	23.1	5.1	2.2	0.5	19	17	12	6
	20	0.65	0.8	3074.4	654.4	23.4	5.9	2.8	1.0	19	17	12	7
	25	0.63		3079.1	668.1	26.4	6.4	3.4	1.0	19	17	12	7
	30	0.68		3086.5	673.6	23.1	4.5	2.2	0.7	19	17	12	7

Table C 4 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A2 0.5 mg/L	5	0.08	0.7	1602.7	311.8	10.8	2.4	0.8	0.2	18	15	11	5
	10			1617.4	319.5	11.4	2.6	0.6	0.1	18	15	11	4
	15			1622.0	311.6	9.6	2.6	1.0	0.3	18	15	10	5
	20	0.25		1614.5	313.4	11.2	2.9	1.0	0.2	18	15	11	5
	25		0.8	1653.6	317.1	11.5	3.0	1.2	0.4	18	15	11	6
	30			1652.7	315.5	11.2	2.5	1.1	0.4	18	15	11	6

Table C 5 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A2 0.25 mg/L	5	0.15		777.1	111.4	2.5	0.4	0.2	0.0	17	14	8	0
	10		0.6	775.4	111.8	2.8	0.4	0.1	0.1	17	14	9	4
	15			793.7	120.5	3.7	0.6	0.4	0.1	17	14	9	4
	20	0.13		758.1	111.5	3.6	0.8	0.4	0.1	17	14	9	4
	25			743.0	115.5	3.1	0.4	0.1	0.0	17	14	9	0
	30			703.7	112.5	2.8	0.5	0.2	0.1	17	14	9	4

Table C 6 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A1 1.0 mg/L	5	0.05		6774.3	1817.3	8.9	n/a	1.6	0.6	20	18	10	6
	10			6654.4	1769.4	4.6	0.3	0.1	0.0	20	18	9	0
	15		0.7	6509.8	1736.6	7.4	1.1	0.6	0.2	20	18	10	5
	20	0.80		6447.0	1724.2	5.5	0.4	0.3	0.1	20	18	10	4
	25			6465.2	1727.7	6.7	0.5	0.1	0.1	20	18	10	4
	30			6388.6	1707.4	6.6	0.6	0.1	0.0	20	18	10	0

Table C 7 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A1 0.5 mg/L	5	0.13		2863.7	722.4	4.2	0.9	0.4	0.0	19	17	9	0
	10			2892.8	740.4	4.1	0.7	0.4	0.1	19	17	9	4
	15		0.6	2893.4	723.4	2.8	0.1	0.0	0.0	19	17	9	0
	20	0.20		3021.1	773.9	4.6	1.3	0.9	0.3	19	17	9	5
	25			3055.4	784.7	2.9	0.6	0.4	0.1	19	17	9	4
	30			3106.6	781.7	3.1	0.3	0.2	0.1	19	17	9	4

Table C 8 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A1 0.25 mg/L	5	0.18		1751.5	437.8	2.2	0.5	0.2	0.1	18	16	8	4
	10			1630.1	406.4	1.7	0.1	0.1	0.1	18	16	8	4
	15		0.6	1537.0	378.2	1.6	0.4	0.4	0.1	18	16	8	4
	20	0.00		1538.6	388.1	5.5	2.6	1.5	0.6	18	16	10	6
	25			1456.2	356.1	1.4	0.5	0.1	0.1	18	16	8	4
	30			1360.4	321.4	1.6	0.1	0.1	0.0	18	16	8	0

Table C 9 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
0.25 mg/L A3 - low Water	5		12.9	1745.0	1077.7	372.2	216.8	134.1	61.4	18	17	16	13
	10		4.6	1226.4	698.9	214.0	128.2	80.0	36.0	17	17	15	12
	15		2.7	784.5	377.3	95.2	54.4	32.6	14.6	17	16	14	11
	20		3.5	743.4	355.1	88.4	51.4	33.5	15.4	17	16	14	11
0.25 mg/L A1 - 5ppm water	5		10.3	2970.8	1529.2	463.1	268.2	167.8	79.4	19	18	16	13
	10		7.8	2476.0	1165.9	321.1	183.1	111.6	51.4	18	17	16	13
	15		7.5	2414.6	1160.8	326.6	190.6	118.7	56.1	18	17	16	13
	20		8.5	n/a	n/a	n/a	n/a	n/a	n/a				
	25		6.7	2446.4	1215.4	351.0	200.3	125.5	56.9	18	17	16	13
	30		5.9	2356.8	1190.8	346.5	196.9	121.4	57.6	18	17	16	13

Table C 10 - Evaluation 3 IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L concentration and free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
RIO 1.0 mg/L	5			6083.8	374.9	0.9	0.1	0.1	0.0	20	16	7	0
	10	0.30		5684.1	338.1	1.1	0.2	0.2	0.1	20	16	7	4
	15			7110.2	464.2	1.2	0.1	0.0	0.0	20	16	7	0
	20	0.43	0.3	4728.3	262.1	0.6	0.2	0.1	0.0	19	15	6	0
	25			9317.1	693.4	1.6	0.1	0.0	0.0	20	17	8	0
	30			7521.5	503.1	1.7	0.0	0.0	0.0	20	16	8	0

Table C 11 - Evaluation 3 IP 564 particle count data for red iron oxide test dust at 1.0 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
RIO 0.5 mg/L	5	0.10		3137.4	143.4	0.6	0.0	0.0	0.0	19	14	6	0
	10			1973.2	79.5	0.2	0.0	0.0	0.0	18	13	5	0
	15			1533.0	62.1	0.3	0.0	0.0	0.0	18	13	5	0
	20	0.08		3065.9	127.8	0.4	0.0	0.0	0.0	19	14	6	0
	25			2409.9	97.8	0.1	0.1	0.0	0.0	18	14	4	0
	30		0.3	1912.1	72.4	0.5	0.1	0.0	0.0	18	13	6	0

Table C 12 - Evaluation 3 IP 564 particle count data for red iron oxide test dust at 0.5 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
RIO 0.25 mg/L	5	0.08		1342.7	47.6	0.3	0.0	0.0	0.0	18	13	5	0
	10		0.3	1614.4	62.2	0.6	0.3	0.2	0.1	18	13	6	4
	15			1446.6	50.6	0.2	0.0	0.0	0.0	18	13	5	0
	20	0.10		1802.1	66.4	0.3	0.1	0.1	0.0	18	13	5	0
	25			2097.1	78.4	0.1	0.1	0.0	0.0	18	13	4	0
	30			2305.1	88.6	0.2	0.1	0.1	0.1	18	14	5	4

Table C 13 - Evaluation 3 IP 564 particle count data for red iron oxide test dust at 0.25 mg/L concentration.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
5 ppm Water	5		3.2	366.1	250.4	94.9	56.7	35.0	16.4	16	15	14	11
	10		2.7	389.5	270.9	105.9	64.2	40.6	19.1	16	15	14	11
	15		2.2	358.2	248.7	95.6	57.0	35.8	16.1	16	15	14	11
	20		2.2	377.1	261.1	97.7	57.4	34.9	16.2	16	15	14	11
	25		2.3	343.3	238.8	90.1	55.2	34.0	15.0	16	15	14	11
	30		2.1	358.9	244.9	93.6	55.3	33.9	16.1	16	15	14	11

Table C 14 - Evaluation 3 IP 564 particle count data for 5 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
10 ppm Water	5		10.4	1737.9	1249.5	474.6	282.2	178.2	82.2	18	17	16	14
	10		11.5	1771.6	1269.4	491.8	295.1	183.0	82.5	18	17	16	14
	15		12.3	1663.1	1185.7	455.3	274.7	174.3	81.6	18	17	16	14
	20		14.4	1528.3	1102.4	421.4	252.6	162.1	77.4	18	17	16	13
	25		10.5	1918.4	1381.4	527.4	319.1	199.2	96.4	18	18	16	14

Table C 15 - Evaluation 3 IP 564 particle count data for 10 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
20 ppm Water	5		14.6	2182.9	1558.8	598.8	358.4	228.0	107.0	18	18	16	14
	10		18.5	2344.1	1672.9	658.0	399.7	257.9	125.1	18	18	17	14
	15		19.9	2344.1	1672.9	658.0	399.7	257.9	125.1	18	18	17	14
	20		15.2	2029.4	1461.5	569.8	347.1	221.6	102.4	18	18	16	14
	25		16.0	2545.4	1825.9	712.2	432.1	278.6	131.9	19	18	17	14
	30		19.3	2504.4	1805.9	701.6	427.3	269.8	133.9	19	18	17	14

Table C 16 - Evaluation 3 IP 564 particle count data for 20 ppm free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
40 ppm Water	5		29.8	4022.4	2912.2	1155.8	702.3	453.4	218.4	19	19	17	15
	10		29.8	4607.5	3320.5	1305.9	788.2	512.6	246.1	19	19	18	15
	15		35.2	5560.1	4010.2	1629.9	1007.0	660.2	330.1	20	19	18	16
	20		34.5	5443.9	3932.9	1585.6	972.3	626.9	312.9	20	19	18	15
	25		36.0	6058.8	4398.6	1784.1	1096.0	711.0	355.4	20	19	18	16
	30		35.5	6011.1	4354.6	1766.5	1078.4	691.4	338.3	20	19	18	16

Table C 17 - Evaluation 3 IP 564 particle count data for 40 ppm free water.

Appendix D Bottle Sample Evaluation

Test Condition	Theoretical mg/L	ASTM D5452 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
ISO 12103-1 A3 medium test dust	1.00	0.80		2210.7	908.2	39.6	9.7	4.5	1.4	18	17	12	8
	1.00	0.40		2017.0	797.2	36.9	8.9	4.5	1.8	18	17	12	8
	0.90	0.60		1516.6	630.9	29.7	7.0	3.3	1.2	18	16	12	7
	0.95	0.80		1570.8	606.2	23.2	4.5	1.9	0.5	18	16	12	6
	1.15	1.20		2557.4	1055.9	32.2	5.8	2.4	0.9	19	17	12	7
	1.10	0.60		2054.6	835.7	38.4	9.4	5.0	2.0	18	17	12	8
	1.00	0.80		1434.5	603.4	31.2	9.2	5.0	2.0	18	16	12	8
	1.05	0.90		1444.5	602.9	31.9	10.3	5.5	2.3	18	16	12	8
	0.85	0.70		1434.5	591.3	26.6	7.4	3.4	1.5	18	16	12	8
	0.85	1.50		1765.7	739.5	33.5	8.3	4.1	1.2	18	17	12	7
	2.00	0.70		4046.5	1593.7	49.0	8.5	3.2	1.0	19	18	13	7
	2.10	1.00		4069.8	1689.4	66.1	12.5	5.0	1.5	19	18	13	8
	2.00	1.10		3920.4	1550.9	60.2	11.8	5.1	1.5	19	18	13	8
	1.90	0.70		3287.1	1343.5	58.0	14.2	7.5	3.0	19	18	13	9
	1.90	1.60		3607.8	1429.5	63.7	13.9	6.3	2.0	19	18	13	8
	2.05	0.60		3738.0	1515.1	56.0	10.3	4.8	2.0	19	18	13	8
	1.95	1.10		3384.1	1508.4	58.8	9.0	3.3	1.2	19	18	13	7
	2.00	1.00		3664.9	1533.9	55.5	9.8	3.8	1.5	19	18	13	8
	1.95	1.20		3350.0	1355.2	45.1	7.9	3.2	1.2	19	18	13	7
	2.00	0.70		3745.7	1550.9	46.0	7.4	2.8	1.2	19	18	13	7

Table D 1 – Bottle sample evaluation IP 564 particle count data for ISO 12103-1 A3 medium test dust at 1 mg/L and 2 mg/L.

Test Condition	Theoretical mg/L	ASTM D5452 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
ISO 12103-1 A2 Fine test dust	1.10	0.90		3662.9	1131.5	39.8	10.6	4.5	1.4	19	17	12	8
	1.10	0.54		3350.5	968.1	34.8	9.5	4.6	1.7	19	17	12	8
	0.98	0.39		2837.7	779.7	23.8	6.4	3.3	1.2	19	17	12	7
	0.95	1.70		3310.6	951.3	26.1	5.1	2.2	1.0	19	17	12	7
	1.05	1.30		3086.9	839.6	15.1	2.5	1.1	0.3	19	17	11	5
	0.90	1.70		2435.6	687.4	24.1	5.7	2.5	1.0	18	17	12	7
	0.90	0.90		1909.0	542.9	19.9	6.7	3.3	1.2	18	16	11	7
	1.10	1.00		2708.2	776.4	30.8	9.0	5.0	1.8	19	17	12	8
	1.05	1.50		2778.2	809.0	29.8	9.5	5.4	2.4	19	17	12	8
	1.15	1.40		3871.8	1112.2	37.9	11.1	5.4	1.6	19	17	12	8
	1.00	0.70		2769.1	774.1	27.4	8.4	4.5	1.5	19	17	12	8
	2.15	2.00		6094.6	1814.7	50.7	12.3	5.4	1.9	20	18	13	8
	2.15	1.60		5843.4	1657.8	48.9	12.5	6.2	3.0	20	18	13	9
	2.15	2.10		5555.4	1679.3	50.1	13.4	5.9	1.8	20	18	13	8
	2.00	1.20		5688.7	1746.4	60.8	17.5	8.2	2.6	20	18	13	9
	1.95	2.00		5143.9	1651.8	54.3	15.2	7.0	2.5	20	18	13	8
	1.90	1.30		5232.0	1556.0	38.8	7.8	3.4	1.1	20	18	12	7
	2.10	1.20		5020.3	1478.3	37.5	8.6	4.3	1.5	20	18	12	8
	2.10	1.90		5708.0	1704.4	51.7	11.8	5.3	1.5	20	18	13	8
	1.95	2.20		6068.7	1824.6	64.7	18.1	8.7	2.7	20	18	13	9
	1.90	2.10		6094.6	1741.1	35.9	5.4	2.1	0.8	20	18	12	7

Table D 2 – Bottle sample evaluation IP 564 particle count data for ISO 12103-1 A2 fine test dust at 1 mg/L and 2 mg/L.

Test Condition	Theoretical mg/L	ASTM D5452 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
ISO 12103-1 A1 ultrafine test dust	1.05	1.30		5830.9	1909.8	10.4	1.4	0.7	0.4	20	18	11	6
	1.05	1.20		5840.3	1802.6	11.6	3.1	2.0	1.0	20	18	11	7
	1.00	1.00		5830.9	1715.2	7.1	1.4	0.8	0.6	20	18	10	6
	1.05	1.40		5725.1	1793.7	10.8	2.8	2.0	1.3	20	18	11	7
	1.05	1.30		7185.4	2274.6	12.4	2.3	1.6	0.9	20	18	11	7
	1.15	1.40		8091.2	2509.4	12.2	3.0	1.9	1.2	20	19	11	7
	0.85	0.80		4864.5	1527.1	9.8	2.6	1.5	1.0	19	18	10	7
	0.95	1.40		5015.8	1575.9	8.2	1.8	1.1	0.7	20	18	10	7
	1.10	1.40		7053.9	2273.8	11.3	2.1	1.3	0.8	20	18	11	7
	0.85	0.40		5917.6	1867.8	9.9	2.5	1.7	1.1	20	18	10	7
	1.95	1.70		11653.1	3992.9	41.4	8.0	3.8	1.6	21	19	13	8
	1.95	1.80		12283.3	3962.3	17.3	2.6	1.6	0.9	21	19	11	7
	1.90	2.10		10304.4	3267.9	16.9	3.2	2.3	1.3	21	19	11	7
	2.05	1.50		10072.5	3619.3	23.1	4.1	2.6	1.5	21	19	12	8
	2.05	1.70		10601.7	3720.5	19.4	3.2	1.9	1.3	21	19	11	7
	1.90	0.70		11882.3	3759.8	13.6	1.9	1.2	0.8	21	19	11	7
	1.85	1.50		12232.7	3860.7	18.2	3.5	2.6	1.9	21	19	11	8
	2.05	0.90		12979.3	4332.8	21.1	3.6	2.0	1.3	21	19	12	7
	2.00	2.50		12151.4	3779.5	18.0	3.1	1.6	1.0	21	19	11	7
	2.05	2.00		12751.9	4132.5	16.5	2.0	1.1	0.8	21	19	11	7

Table D 3 – Bottle sample evaluation IP 564 particle count data for ISO 12103-1 A1 ultrafine test dust at 1 mg/L and 2 mg/L.

Appendix E Test Dust and Free Water Test Dust Evaluation

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A2 0.25 mg/L	0		0.6	1324.2	309.5	5.9	1.4	0.6	0.2	18	15	10	5
	3	0.08		1359.9	324.6	6.1	1.6	0.6	0.1	18	16	10	4
	5	0.13		1304.4	307.1	7.4	1.6	0.6	0.0	18	15	10	0
7.1 ppm H2O	0			7092.1	4558.0	426.5	119.9	47.4	6.7	20	19	16	10
	2		6.7	6329.4	4101.3	403.5	119.8	44.9	6.5	20	19	16	10
	4			6794.2	4407.1	442.7	127.1	50.1	7.4	20	19	16	10
	8		7.2	6898.7	4420.4	444.6	129.4	47.8	7.2	20	19	16	10
	11			6824.3	4368.7	440.9	120.5	47.9	7.4	20	19	16	10
	13		8.1	7020.2	4491.9	455.1	126.5	46.1	7.0	20	19	16	10
	18		7.5	6731.4	4308.1	437.3	127.5	48.6	8.6	20	19	16	10
	23			6871.2	4395.3	445.2	135.6	51.1	8.0	20	19	16	10
	25		6.2	6937.2	4431.4	477.6	139.2	55.9	8.8	20	19	16	10
A2 0.25 mg/L - 7.6ppm water	0		8.0	7393.2	3655.5	325.4	92.9	36.9	6.1	20	19	16	10
	3		7.2	7215.8	3543.5	318.9	93.0	34.5	5.6	20	19	15	10
A2 0.25 mg/L -	0		8.8	9057.1	4791.2	451.4	129.4	50.7	7.9	20	19	16	10
	2			8844.6	4634.7	433.9	124.3	48.8	7.5	20	19	16	10

Table E 1 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.25 mg/L concentration with low concentration free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A2 0.25 mg/L	0		0.6	1324.2	309.5	5.9	1.4	0.6	0.2	18	15	10	5
	3	0.08		1359.9	324.6	6.1	1.6	0.6	0.1	18	16	10	4
	5	0.13		1304.4	307.1	7.4	1.6	0.6	0.0	18	15	10	0
40 ppm H2O	0		39.6	27380.7	18466.9	2325.0	668.9	267.4	41.8	22	21	18	13
	2			26435.7	17863.6	2243.2	648.6	259.2	40.4	22	21	18	13
	4		40.7	28121.3	19040.8	2480.6	733.4	300.3	48.6	22	21	18	13
	8		39.9	26581.9	17996.9	2329.4	684.1	286.0	45.4	22	21	18	13
	11		40.6	26790.7	18139.6	2328.1	698.2	286.3	45.8	22	21	18	13
	15		38.2	26919.8	18277.4	2379.4	714.1	295.5	47.8	22	21	18	13
A2 0.25 mg/L - 33.6 ppm water	0		33.9	26813.1	17067.6	2095.9	596.9	244.2	40.0	22	21	18	12
	3		33.3	26501.2	16958.1	2104.3	621.9	255.1	39.1	22	21	18	12
	6			26347.5	16840.0	2044.5	601.2	241.4	38.9	22	21	18	12

Table E 2 – Evaluation 1 IP 564 particle count data for ISO 12103-1 A2 fine test dust at 0.25 mg/L concentration with high concentration free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
RIO 0.25 mg/L	0		0.7	9304.4	1285.5	3.1	0.4	0.1	0.1	20	17	9	4
	2			8908.9	1236.1	8.3	1.9	0.9	0.1	20	17	10	4
	4	0.15		8548.0	1093.1	1.8	0.3	0.1	0.0	20	17	8	0
	8			9146.1	1224.4	2.3	0.4	0.1	0.0	20	17	8	0
	11			8693.1	1110.2	4.0	0.6	0.4	0.1	20	17	9	4
	13	0.17		8774.1	1125.9	2.1	0.4	0.3	0.2	20	17	8	5
7.1 ppm H2O	0			7092.1	4558.0	426.5	119.9	47.4	6.7	20	19	16	10
	2		6.7	6329.4	4101.3	403.5	119.8	44.9	6.5	20	19	16	10
	4			6794.2	4407.1	442.7	127.1	50.1	7.4	20	19	16	10
	8		7.2	6898.7	4420.4	444.6	129.4	47.8	7.2	20	19	16	10
	11			6824.3	4368.7	440.9	120.5	47.9	7.4	20	19	16	10
	13		8.1	7020.2	4491.9	455.1	126.5	46.1	7.0	20	19	16	10
	18		7.5	6731.4	4308.1	437.3	127.5	48.6	8.6	20	19	16	10
	23			6871.2	4395.3	445.2	135.6	51.1	8.0	20	19	16	10
	25		6.2	6937.2	4431.4	477.6	139.2	55.9	8.8	20	19	16	10
RIO 0.25 mg/L 5ppm H2O	0			11887.4	3498.7	247.6	69.7	27.5	4.8	21	19	15	9
	3			11324.7	3216.9	229.3	70.4	27.2	3.8	21	19	15	9
	4			11422.4	3282.5	234.1	67.4	26.0	4.3	21	19	15	9

Table E 3 – Evaluation 1 IP 564 particle count data for Red Iron Oxide test dust at 0.25 mg/L concentration with free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A1 0.25 mg/L	5	0.1075		2243.6	603.8	4.6	1.3	0.6	0.5	18	16	9	6	2847.0	1221.6	7.9	0.4	0.0	0.0	19	17	10	0
	10		0.5	2195.9	598.6	3.9	1.6	1.0	0.6	18	16	9	6	2831.3	1220.4	9.5	0.7	0.2	0.1	19	17	10	4
	15			2209.5	593.8	3.8	0.8	0.4	0.2	18	16	9	5	2794.7	1194.8	7.0	0.7	0.2	0.1	19	17	10	4
	20	0.2400		2192.5	592.5	3.4	0.9	0.6	0.3	18	16	9	5	2777.5	1187.5	7.7	0.1	0.3	0.2	19	17	10	5
	25			2221.0	603.1	3.8	1.1	0.6	0.4	18	16	9	6	2757.3	1174.3	7.2	0.6	0.1	0.1	19	17	10	4
Water 5 ppm	5		2.2	3576.1	1986.1	159.0	31.3	10.1	2.2	19	18	14	8	2087.6	1761.0	524.5	114.5	53.8	22.9	18	18	16	12
	10		2.3	3680.4	2003.6	167.5	40.1	12.9	3.9	19	18	15	9	2051.3	1724.4	521.2	115.1	53.2	21.7	18	18	16	12
	15		2.3	4025.4	2227.1	191.6	43.9	13.9	3.0	19	18	15	9	2205.2	1859.5	563.7	121.4	57.9	24.5	18	18	16	12
	20		2.9	4281.1	2383.1	208.4	43.8	12.4	2.3	19	18	15	8	2229.5	1876.4	566.7	120.2	56.0	22.9	18	18	16	12
	25		1.4	4107.0	2281.5	202.5	44.3	12.3	2.6	19	18	15	9	2042.5	1717.3	517.0	109.8	50.6	21.2	18	18	16	12
	30		2.7	4526.8	2511.1	217.5	50.2	15.4	3.4	19	19	15	9	2390.5	2017.1	606.5	131.1	59.5	24.0	18	18	16	12
A1 0.25 mg/L - 5 ppm Water	5		4.0	7918.6	3839.4	266.4	57.3	19.7	5.8	20	19	15	10	6420.1	4399.4	999.7	198.5	86.1	35.1	20	19	17	12
	10		4.0	7753.6	3822.9	247.9	47.5	14.3	2.8	20	19	15	9	5760.1	3952.0	878.4	167.4	73.3	29.0	20	19	17	12
	15		3.8	7108.1	3500.1	233.6	45.5	13.2	2.9	20	19	15	9	5524.0	3762.2	841.0	159.1	71.7	28.7	20	19	17	12
	20		2.3	7082.4	3472.9	229.5	45.3	12.6	2.6	20	19	15	9	5311.7	3554.7	761.6	143.3	61.9	24.5	20	19	17	12
	25		2.7	6478.1	3131.7	203.9	41.1	10.5	2.4	20	19	15	8	4959.7	3258.7	682.0	131.8	59.1	22.4	19	19	17	12
	30		3.3	6083.7	2893.7	180.9	35.1	9.1	1.4	20	19	15	8	4670.3	3011.9	613.4	117.7	51.4	19.8	19	19	16	11

Table E 4 – Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L with low concentration free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code				ASTM D7619, IP 565						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30	≥ 4μm	≥ 6μm	≥ 14μm	≥ 21μm	≥ 25μm	≥ 30μm	4	6	14	30
A1 1.0 mg/L	5	0.3475		5991.9	1688.6	16.0	4.7	2.9	1.7	20	18	11	8	6843.2	3123.9	24.5	1.6	0.5	0.2	20	19	12	5
	10			4894.5	1354.4	11.4	3.0	1.9	1.0	19	18	11	7	5709.2	2558.3	22.7	1.9	0.4	0.2	20	19	12	5
	15		0.5	4060.9	1119.9	11.7	3.4	1.7	0.8	19	17	11	7	4747.3	2107.7	18.7	2.3	1.2	0.7	19	18	11	7
	20	0.3525		3837.3	1074.7	9.1	2.0	1.0	0.3	19	17	10	5	4643.3	2060.4	18.8	1.6	0.4	0.2	19	18	11	5
	25			4900.9	1377.0	9.9	2.4	0.6	0.3	19	18	10	5	6336.7	2835.8	22.2	1.5	0.3	0.1	20	19	12	4
	30			5604.5	1577.9	10.5	2.9	1.4	0.8	20	18	11	7	6689.3	3003.7	23.7	1.6	0.4	0.2	20	19	12	5
10 ppm Water	5		3.6	5749.7	3222.8	299.1	65.1	20.6	3.9	20	19	15	9	3088.6	2610.7	785.5	172.2	79.1	32.3	19	19	17	12
	10		6.6	8526.3	4836.2	473.4	110.2	33.6	6.1	20	19	16	10	4534.3	3848.7	1145.0	250.0	117.0	46.7	19	19	17	13
	15		8.1	9585.4	5490.1	555.4	130.2	39.6	5.4	20	20	16	10	5226.0	4440.1	1346.9	292.1	135.6	54.5	20	19	18	13
	20		8.2	10814.1	6260.5	640.0	144.5	44.9	6.4	21	20	16	10	6252.8	5312.4	1607.1	345.5	159.5	62.9	20	20	18	13
	25		11.3	11856.1	6849.4	730.4	171.3	53.7	9.8	21	20	17	10	7143.8	6055.1	1833.6	400.3	182.3	76.0	20	20	18	13
	30		10.1	12804.6	7461.9	816.2	185.4	58.1	10.9	21	20	17	11	7225.4	6141.3	1855.1	404.1	183.6	75.4	20	20	18	13
A1 1.0 mg/L - 10 ppm Water	5		7.9	13091.9	6150.3	455.9	95.5	30.1	8.0	21	20	16	10	13034.4	8307.0	1578.3	397.7	204.3	98.4	21	20	18	14
	10		8.8	13022.9	6208.8	503.4	115.5	36.0	7.8	21	20	16	10	13074.2	8542.9	1704.6	431.1	216.1	104.5	21	20	18	14
	15		8.1	12681.1	6114.9	488.9	107.8	31.2	5.6	21	20	16	10	12302.6	8056.7	1634.5	410.0	204.8	95.5	21	20	18	14
	20			12728.4	6213.1	497.3	104.0	32.6	5.9	21	20	16	10	11766.7	7814.2	1632.8	392.2	194.1	87.8	21	20	18	14

Table E 5 – Evaluation 2 IP 564 and ASTM D7619 (IP 565) particle count data for ISO 12103-1 A1 ultrafine test dust at 0.25 mg/L with medium concentration free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A3 0.25 mg/L	5	0.15		464.5	144.7	5.6	1.0	0.3	0.1	16	14	10	4
	10			453.1	137.1	6.3	1.2	0.4	0.1	16	14	10	4
	15		0.8	438.4	137.4	6.4	0.9	0.2	0.1	16	14	10	4
	20	0.2		479.6	149.9	6.9	1.1	0.4	0.2	16	14	10	5
	25			476.9	145.7	5.9	0.6	0.3	0.0	16	14	10	0
	30			486.0	153.2	6.9	1.6	0.6	0.1	16	14	10	4
5 ppm Water	5		3.2	366.1	250.4	94.9	56.7	35.0	16.4	16	15	14	11
	10		2.7	389.5	270.9	105.9	64.2	40.6	19.1	16	15	14	11
	15		2.2	358.2	248.7	95.6	57.0	35.8	16.1	16	15	14	11
	20		2.2	377.1	261.1	97.7	57.4	34.9	16.2	16	15	14	11
	25		2.3	343.3	238.8	90.1	55.2	34.0	15.0	16	15	14	11
	30		2.1	358.9	244.9	93.6	55.3	33.9	16.1	16	15	14	11
A3 0.25 mg/L - low Water	5		12.9	1745.0	1077.7	372.2	216.8	134.1	61.4	18	17	16	13
	10		4.6	1226.4	698.9	214.0	128.2	80.0	36.0	17	17	15	12
	15		2.7	784.5	377.3	95.2	54.4	32.6	14.6	17	16	14	11
	20		3.5	743.4	355.1	88.4	51.4	33.5	15.4	17	16	14	11

Table E 6 – Evaluation 3 IP 564 particle count data for ISO 12103-1 A3 medium test dust at 0.25 mg/L with free water.

Test Condition	Time	ASTM D2276 mg/L	ASTM D3240 PPM	IP 564						ISO 4406 Code			
				≥ 4 μm	≥ 6 μm	≥ 14 μm	≥ 21 μm	≥ 25 μm	≥ 30 μm	4	6	14	30
A1 0.25 mg/L	5	0.175		1751.5	437.8	2.2	0.5	0.2	0.1	18	16	8	4
	10			1630.1	406.4	1.7	0.1	0.1	0.1	18	16	8	4
	15		0.6	1537.0	378.2	1.6	0.4	0.4	0.1	18	16	8	4
	20	0.0		1538.6	388.1	5.5	2.6	1.5	0.6	18	16	10	6
	25			1456.2	356.1	1.4	0.5	0.1	0.1	18	16	8	4
	30			1360.4	321.4	1.6	0.1	0.1	0.0	18	16	8	0
10 ppm Water	5		10.4	1737.9	1249.5	474.6	282.2	178.2	82.2	18	17	16	14
	10		11.5	1771.6	1269.4	491.8	295.1	183.0	82.5	18	17	16	14
	15		12.3	1663.1	1185.7	455.3	274.7	174.3	81.6	18	17	16	14
	20		14.4	1528.3	1102.4	421.4	252.6	162.1	77.4	18	17	16	13
	25		10.5	1918.4	1381.4	527.4	319.1	199.2	96.4	18	18	16	14
A1 0.25 mg/L - 5ppm water	5		10.3	2970.8	1529.2	463.1	268.2	167.8	79.4	19	18	16	13
	10		7.8	2476.0	1165.9	321.1	183.1	111.6	51.4	18	17	16	13
	15		7.5	2414.6	1160.8	326.6	190.6	118.7	56.1	18	17	16	13
	20		8.5	n/a	n/a	n/a	n/a	n/a	n/a				
	25		6.7	2446.4	1215.4	351.0	200.3	125.5	56.9	18	17	16	13
	30		5.9	2356.8	1190.8	346.5	196.9	121.4	57.6	18	17	16	13

Table E 7 – Evaluation 3 IP 564 particle count data for ISO 12103-1 A1 fine test dust at 0.25 mg/L with free water.